High Frequency Alternator, Power Frequency Conversion (HFA-PFC) Technology for Lightweight Tactical Power Generation.

Final Report

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13. ABSTRACT (*Maximum 200 words*)

This document describes Variable Speed High Frequency Alternators for diesel engine gen-sets with variable speeds in the range of from 600 RPM to 3,600 RPM and High Frequency Alternators for gas turbine gen-sets with variable speeds in the range of from 8,700 RPM to 60,000 RPM.

This document also describes two-step and single-step Power Frequency Converters for conversion of the variable high frequency AC power to MIL-STD frequency and voltage (such as 60 Hz or 400 Hz and 120 VAC). Described converters utilize insulated gate bipolar transistors (IGBTs) for smaller gen-sets and SCRs for larger gen-sets.

Described HFA-PFC Technology can be used in all required power ranges from 0.5 kW to powers of 1,000 kW and more.

14. SUBJECT TERMS

High Frequency Alternators; Generator Sets; High Speed Generators; Electronic Power Conversion; Inverters; Cycloconverters

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C. Results of the Phase I Work

The topic for this project:

TOPIC: A94-072 TITLE: High Frequency Alternator, Power Frequency Conversion (HFA-PFC) Technology for Lightweight Tactical Power Generation

Point of Contact: CECOM

CATEGORY: Advanced Development

OBJECTIVE: To explore the potential for generator set size and weight reduction through the use of integrated power components. Components include a lightweight, High Frequency Alternator (HFA) coupled with Power Frequency Conversion (PFC) components to produce MIL-STD power (such as 60 Hz, 120 VAC). A control system would maintain the proper output frequency and voltage for transient and steady state load conditions and changing engine speed.

DESCRIPTION: There exists excellent potential for reducing the size and weight of DOD tactical generator sets using the HFA-PFC concept. In addition to potential weight reductions, this concept de-couples the output frequency from engine speed so that the engine can run at a speed dictated by the operational environment (higher speeds for maximum power or lower speeds for maximum fuel efficiency and reliability). Such performance flexibility and size/weight reductions would improve the operational performance of the gen- sets due to improved deployability and mobility, and reduced handling requirements. Such performance goals match Army requirements and scenarios for highly dynamic "shoot and scoot" situations expected in future conflicts. A weight driver for current DoD gen-sets is the 60 Hz alternator which is generally driven at 1,800 rpm by the engine. Alternator size and weight decrease dramatically when speed and frequency are increased. Engine power density can also be increased because the engine can be run at its optimum power speed for high power loads. The PFC components condition alternator power to produce MIL-STD frequency and voltage (such as 60 Hz and 120 VAC) independent of engine speed. Commercial 1,800 rpm, 60 Hz alternators represent static technology with little performance improvements foreseeable. Power semiconductors (the major component of the PFC) are a rapidly advancing technology with excellent potential for further size/weight reductions in the future.

Phase I: The contractor shall determine optimum HFA-PFC design options for the following power ranges: 5-30 kW, 30-100 kW and 100-1,000 kW. Determine the optimum HFA design and the optimum power semiconductor technology and topology for the given power ranges.

Phase II: The Government can determine the optimum power range(s) to be explored during Phase II based on Phase I results analysis and review.) The contractor shall fabricate and test prototype full scale or sub-scale (as appropriate) versions of the HFA-PFC. The mobility and deployability benefits due to weight reductions shall be quantified along with studies to determine producibility and logistics issues associated with HFA-PFC based gen-sets.

Potential Commercial Market: HFA-PFC technology would be applicable to the commercial gen-set market segments where size/weight and/or fuel efficiency are key concerns. The major life cycle cost element of commercial gen- sets is fuel cost, so being able to produce 60 Hz at the most efficient engine speed could be a distinct advantage.

Current military gen-sets use 60 Hz or 400 Hz brushless alternators that are generally driven by diesel engines at 1,800 or 2,000 RPM, respectively. Diesel engines are used because they are the best in fuel economy compared to all other existing engines.

Diesel fuel storage and handling is less hazardous than with gasoline, and logistic burdens are reduced by having a common fuel for a large number of users.

Some quantity of military gen-sets with gas turbine engines exists, for example, 60 kW gen-set EMU-30/E (MEP-404B), but their specific fuel consumption (S.F.C.) is about 1.4 lbs/HP·hr compared to .375 lbs/HP·hr for diesel gen-sets [1].

The existing price of the small gas turbine engines is over $120,000 for each unit, or more than ten times more expensive compared to all other types of existing engines, including rotary engines [2].

The existing military gen-sets with gas turbine engines are used mostly by the US Air Force, but based on a new global situation when future wars will be similar to the Persian Gulf War, the US Army should have the same mobility as the US Air Force, and military gen-sets with gas turbine engines should be taken into consideration.

Army wide assets of mobile electric power generators with diesel engines in the range from 0.5 kW to 200 kW are shown on the Chart 1, page 6 [3].

Engines

The existing Tactical Quiet Generator Sets (TQGs) with diesel engines have a constant shaft speed of 1,800 RPM and direct coupling of the engine with an alternator.

The technical data about the existing TQGs in the power range from 5 kW to 60 kW is shown in the Table 1, page 7 [4,5,6].

The current manufacturer of these TQGs is Libby Corp., Kansas City, Missouri.

The technical data about the engines manufactured by John Deere and used in existing 30 kW and 60 kW TQGs isn't available because their diesels don't comply with military engine emission regulations and, at least for 5 years, will not be available for military applications or, at least, for new design. We got this information from Mr. Julio De Silva, a manager with John Deere.

Moreover, he also said that two gentlemen, Mr. Jerry Wilson and Col. James Cross, from DoD Project Manager Mobile Electric Power now are working with John Deere to somehow solve the problem.

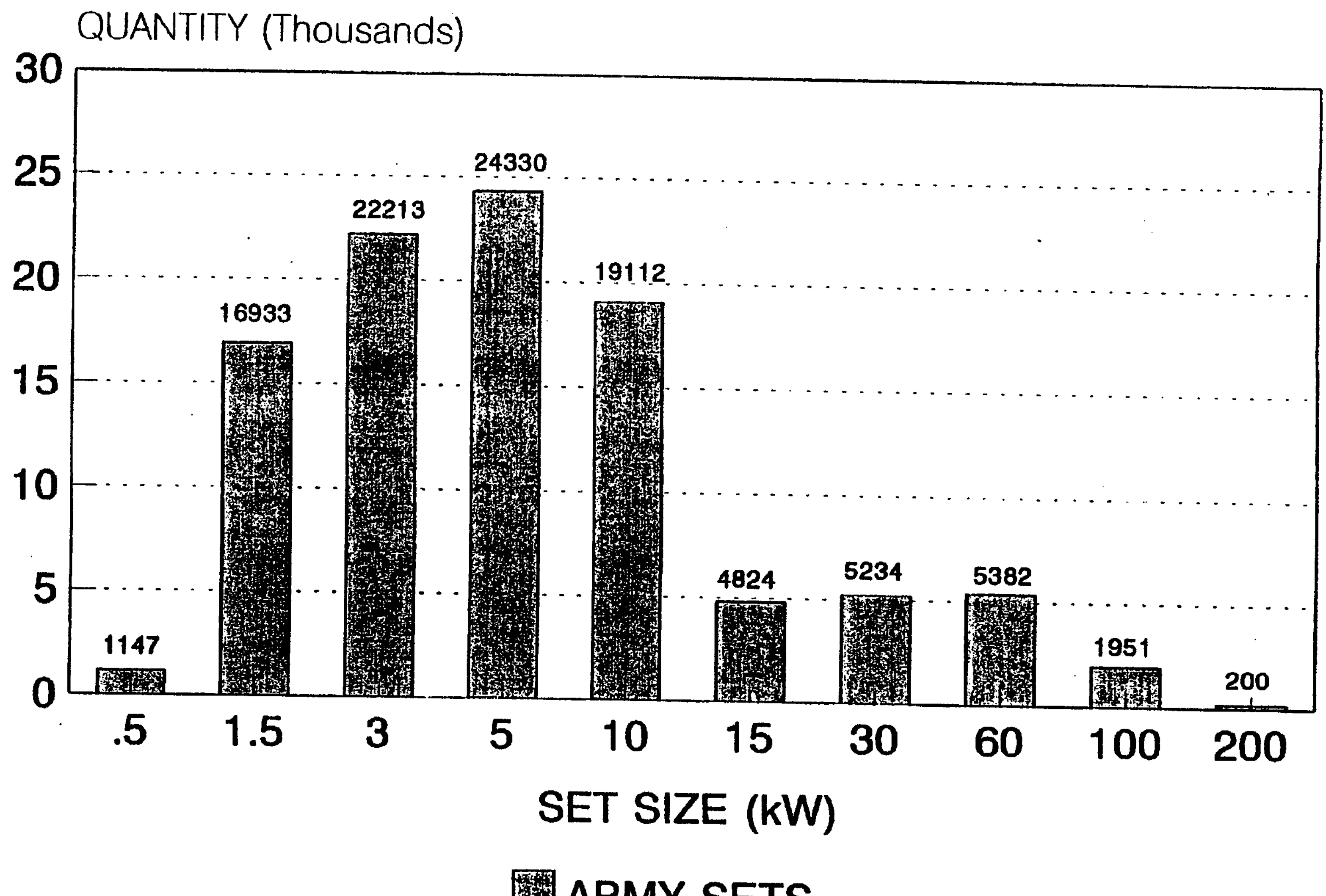
Diesel engines are the best in fuel economy. However, the weight to HP ratio for the diesel engines is from 6-8 lbs/HP (for a few hundred HP diesels) to 9-10 lbs/HP (for small diesel engines with HP less than 100 HP) [7].

Small diesel engines with HP less than 30 HP have a specific fuel consumption (S.F.C.) of 0.43-0.440 lbs/HP·hr. Larger diesel engines with HP above 30 HP up to 1,500 HP (1,000 kW gen-sets) have a specific fuel consumption (S.F.C.) of 0.350-0.375 lbs/HP·hr [4,5].

Some technical data about the diesel engines utilized in existing Tactical Quiet Generator Sets (TQGs) in the power range from 5 kW to 15 kW is shown in the Table 2, page 8. These gen-sets have a fixed rotor speed of 1,800 or 2,000 RPM because of requirement for constant output frequency of 60 Hz or 400 Hz.

The calculation of the maximum continuous output power of the gen-sets at the maximum continuous engine speeds (Table 2, page 8) were based on an assumption that output voltage and frequency could be converted to the desired voltage and frequency without any losses.

MOBILE ELECTRIC POWER GENERATORS
ARMY WIDE ASSETS



GRAND TOTAL 101,326 SETS

DATA FOR (1993)

Table 1.

Rated Power, kW and Frequency, Hz	MEP No.	Size, L x W x H, inches	Size, Cube, cu.ft.	Weight, lbs
5 kW, 60 Hz*[1]	MEP-802A	50.32 x 31.72 x36.00	33.25	888
5 kW, 400 Hz	MEP-812A	50.32 x 31.72 x36.00	33.25	911
10 kW, 60 Hz*[1]	MEP-803A	61.75 x 31.72 x 36.00	40.81	1182
10 kW, 400 Hz	MEP-813A	61.75 x 31.72 x 36.00	40.81	1220
15 kW, 60 Hz*[2]	MEP-804A	69.25 x 35.25 x 54.00	76.28	2124
15 kW, 400 Hz	MEP-814A	50.32 x 31.72 x36.00	76.28	2238
30 kW, 60 Hz*[3]	MEP-805A	79.25 x 35.25 x 54.00	87.30	3006
30 kW, 400 Hz	MEP-815A	79.25 x 35.25 x 54.00	87.30	3015
60 kW, 60 Hz*[3]	MEP-806A	86.50 x 35.25 x 58.00	102.34	4063
60 kW, 400 Hz	MEP-816A	86.50 x 35.25 x 58.00	102.34	4153

NOTES: *[1] Diesel engines manufactured by Lister-Petter, Inc.;
*[2] Diesel engines by Isuzu Diesel of North America;
*[3] Diesel engines by John Deere Engine Works;

Table 2.

Rated Power of Gen-Set, kW	5 kW	10 kW	15 kW
MEP No.	MEP-802A & MEP-812A	MEP-803A & MEP-813A	MEP-804A & MEP-814A
Minimum Continuous Speed, RPM	1,500	1,500	1,500
Max. Engine Continuous HP (kW) at 1,800 RPM	11.0 (8.2)	16.5 (12.3)	31 (23.1)
Max. Continuous Output Power of Gen-Set, kW*[1] (%), at 1,800 RPM	7.4 (148%)	11.1 (111%)	20.8 (139%)
Max. Engine Continuous HP (kW) at max. RPM, HP (kW) /RPM	18.8 (14) /3,600	28.2 (21) /3,600	45 (33.6) /3,000
Max. Continuous Output Power of Gen-Set, kW*[1] (%), at max. RPM	12.6 (252%)	18.9 (189%)	30.2 (201%)
Ratio of Max. Power Increase *[2], (%)	170.3(%)	170.3(%)	145.2(%)

NOTES:

*[1] The calculations are based on the assumption that the efficiency of the alternator is 90%; The ratio in the parentheses is calculated by comparing the maximum continuous output power of the gen-set at 1,800 RPM to the rated power of gen-set;

The shown maximum continuous output power of gen-set is limited by the maximum continuous output power of the alternator that is about rated power;

*[2] The ratio is calculated by comparing the maximum continuous output power of the gen-set at the maximum engine speed to the maximum continuous output power of the gen-set at 1,800 RPM.

The losses in frequency converters could be about 2-6% for AC-DC-AC type of converters and about 1-2% for zero switching AC- AC type of converters.

The rated output power of all engines is listed by manufactures with a tolerance of +/- 5%. In this case, the losses of about 1-2% could be omitted.

From Table 2, page 8, it can be seen that the maximum continuous output power of the gen-sets at maximum engine speeds of 3,000-3,600 RPM could be about twice more than the gen-set's rated output power at an engine speed of 1,800 RPM. That is, the utilization of the High Frequency Alternator, Power Frequency Conversion (HFA-PFC) Technology for Lightweight Tactical Power Generation can **double the maximum continuous output power** while the size and weight of gen-sets could be the same or even lighter and smaller compared to conventional TQG gen-sets.

The size and weight of the small TQGs in the power range from 5 kW to 15 kW could be the same or lighter and smaller because conventional alternators will be replaced with an assembly of the gearbox multipliers and the high speed, high frequency alternators which will be mounted as shown on Figure 1, page 10 .The shown assembly will be much lighter than the conventional 1,800 RPM alternator. Even after the installation of the frequency converters, the size and weight of the existing 5-15 kW gen-sets will be about the same as existing military TQGs or even lighter and smaller.

Gen-sets larger than 15 kW, based on the HFA-PFC Technology, will be significantly smaller and lighter compared to conventional gen-sets of the same rated power.

Alternators can have a continuous speed of 3,600 RPM to provide a 60 Hz output without any technical problems, but a speed of 3,600 RPM is too high for conventional military grade heavy duty diesels with BHP more than 50 HP.

Some small diesel engines with BHP in the range from 10 HP to 40 HP can run at a continuous speed of 3,600 RPM, for example, LPW line of diesels from Lister-Petter and KC, KR line of diesels from Isuzu Diesel of North America, but their specific fuel consumption (S.F.C.) at 3,600 RPM is 15% higher compared to their S.F.C. at 1,800 RPM [4,5]

Medium size diesel engines with BHP in the range from 40 HP to 250 HP have the maximum continuous speeds of about 2,500-3,000 RPM [5].

Diesel engines with BHP in the range of 250 HP and up have maximum continuous speeds of about 1,800-2,300 RPM [7,17].

All the advantages of implementation of the HFA-PFC Technology in gen-sets with diesel engines can be achieved only if some kind of speed multiplier between the engine and alternator would be utilized as shown on Figure 1, page 10.

From all the possible types of the speed multipliers only the gearbox multipliers have the required reliability even if they could be more expensive compared to other types of speed multipliers.

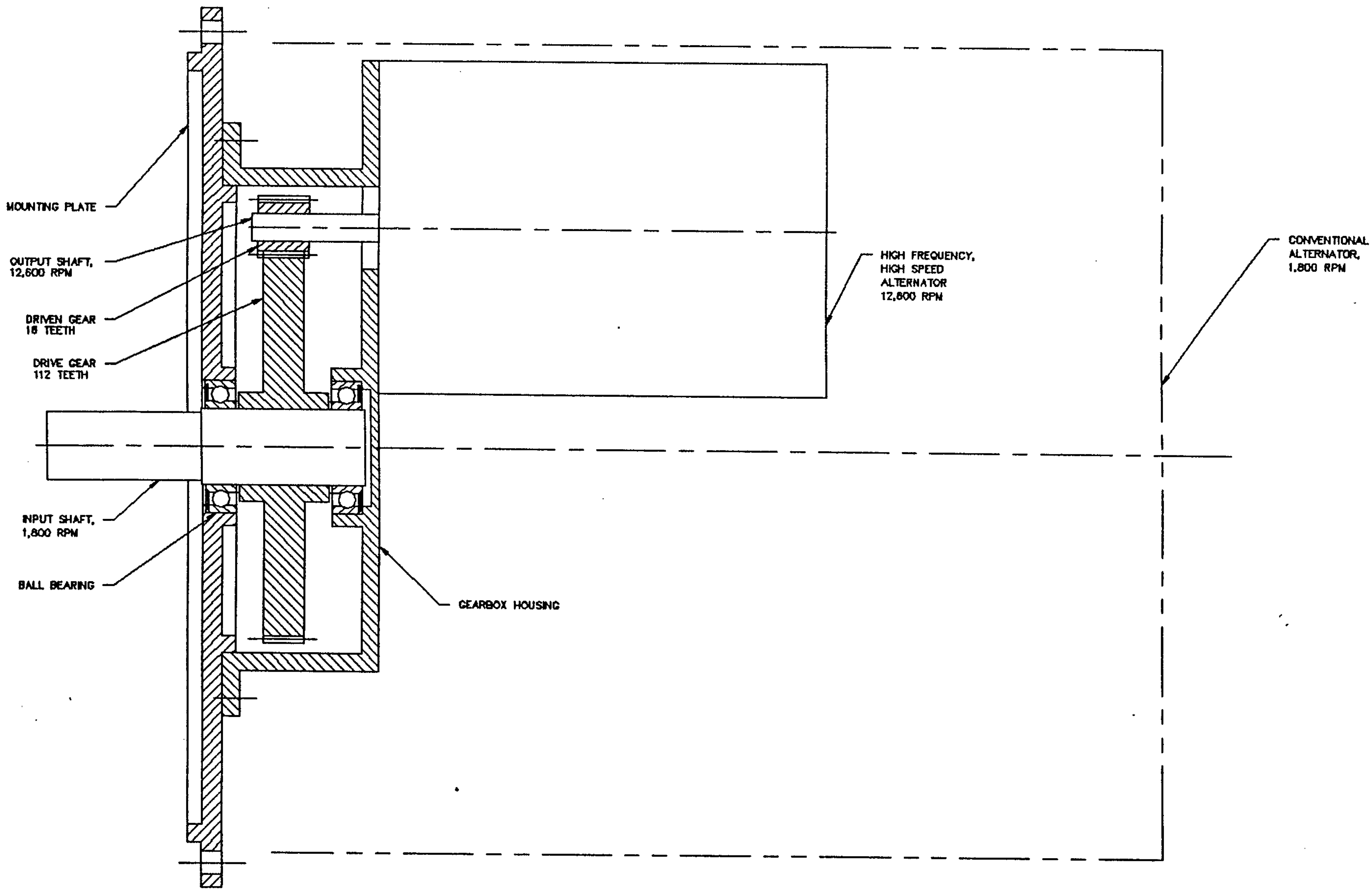


FIGURE 1. GEARBOX—MULTIPIER

ARMY-02.DWG

The gearbox multiplier that is shown on Figure 1, page 10, has an output speed/input speed ratio of 7 and 11 kW output power to drive 10 kW alternator at 12,600 RPM. The diesel continuous crankshaft speed is 1,800 RPM.

At a continuous crankshaft speed of 3,600 RPM, an alternator will have a shaft speed of 25,200 RPM and continuous output power of 18.9 kW. That is, almost twice more compared to a conventional 10 kW gen-set.

The gearbox multiplier that is shown on Figure 1, page 10, isn't just a sketch to illustrate the idea of the HFA-PFC Technology. This is rather a preliminary assembling drawing with all the necessary dimensions based on preliminary calculations. The mentioned drawing can be used either for a prototype with welded housing or later for casted housing.

If for any reason, the mentioned alternator speed range of the multiplier will be too high, this range could be shifted to lower speeds with some compromise in the size and weight.

The rotary engines have a weight about twice lighter and a size about twice smaller compared to diesel engines as shown on page 12.

Some information about rotary engines from Rotary Power International (RPI) is enclosed shown on pages 13 and 14.

RPI rotary engines have a maximum fuel efficiency in the speed range from 3,500 RPM to 5,000 RPM and a maximum rated power at the shaft speed of 6,000 RPM.

Their minimum specific fuel consumption (S.F.C.) is **0.450 lbs/HP·hr** or *equivalent to diesel*, as stated in their catalog.

However, this is true only for small engines with BHP in the range from 10 HP to 40 HP when diesel engines have a S.F.C. of **0.440 lbs/HP·hr.**

Larger diesel engines have a S.F.C. of **0.350-375 lbs/HP·hr.**

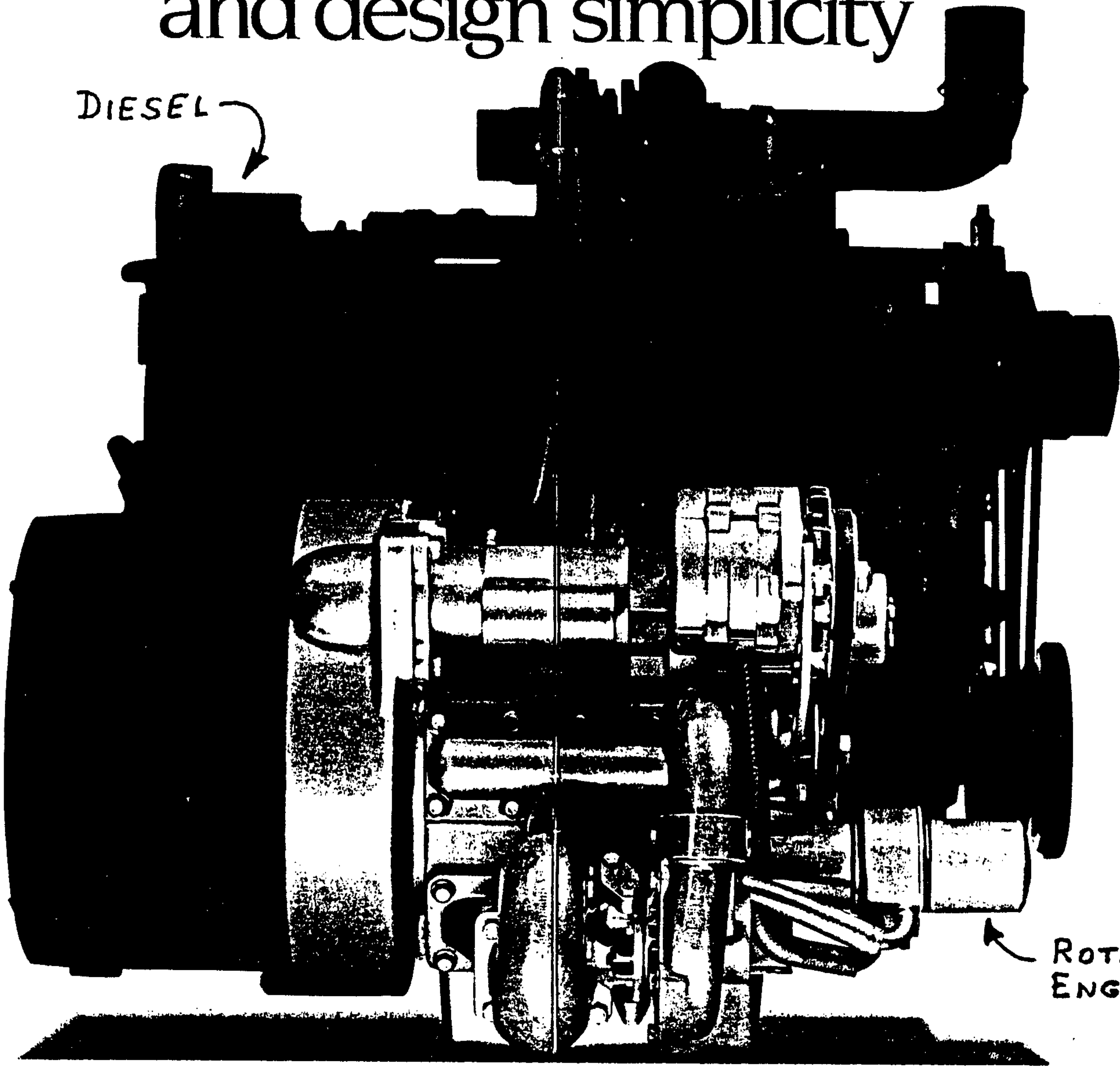
Larger rotary engines have a S.F.C. of about 25% higher compared to diesel engines.

The rated engine power for the first generation of RPI rotary engines is shown on pages 13 and 14. The rated engine power of the second generation (the "power growth version") will be twice as much as the rated engine power for the first generation and is shown in parentheses on page 13.

The mentioned rotary engines were developed by RPI for military applications, and engines of the first generation are scheduled for production in 1997.

However, the development of the engines of the second generation is beyond schedule and their availability might be expected sometime in 1998-99 or beyond (in July 1992, the RPI planned to introduce them in 1995).

Welcome to a new era in compact power and design simplicity



In the evolution of power sources, few engines can match the potential of the SCORE rotary engine. This Stratified Charge Omnivorous Rotary Engine, with its exceptional power density and multi-fuel capability, is the ideal choice to meet your logistic and tactical needs. Offering numerous benefits to the user, the rotary engine gives the design engineer something even more important.

Greater design freedom.

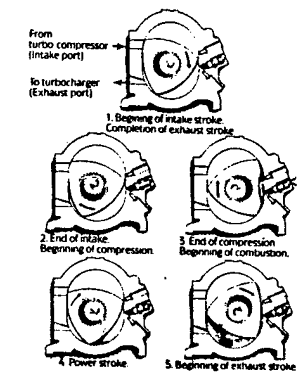
You know how tough it can be to plan around bulky, inefficient power plants. The SCORE rotary engine offers big power in a compact size. As a result, the SCORE engine's lower profile helps you accomplish a number of goals... such as:

- reduced target size of vehicle
- reduced armor needs
- or, adding more available space for personnel or ordnance without increasing outer envelope size.

In other words, a SCORE rotary engine will help trim unwanted fat from your designs, while maintaining the performance and reliability standards you expect. Producing rotary motion directly, the SCORE engine's design eliminates up to 50 percent of the bulk and weight needed by reciprocating diesels, while vastly improving on the efficiency over that of gas turbines.

The rotary engine is unmatched in its design simplicity... an important plus for your entire operation. The turbocharged SCORE engine uses a rotor with three combustion faces. These faces (which are the equivalent of pistons in a reciprocating engine) provide for a 270 degree power impulse (stroke) during each crank revolution. The rotor fits closely around the crank eccentric, but it rotates only at one-third of the crankshaft speed.

HERE'S HOW IT WORKS



SCORE rotary engine design achieves "4-stroke" operating economies with a power pulse every revolution.

The SCORE rotary engine's low rotating inertia reduces the engine's acceleration time from idle to maximum-torque speed. Add the engine's high torque output characteristics and you get a very responsive engine. This is important, because the comparatively low lag-time helps improve vehicle mobility.

The result is smooth, high torque for exceptional performance.

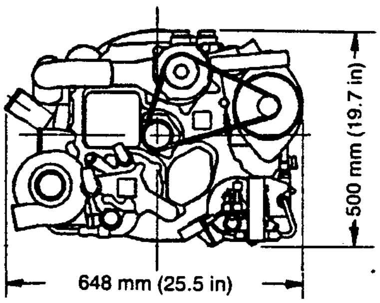
This comparison of the compact SCORE rotary engine with a diesel of similar power output is a dramatic example of the engine's power density.

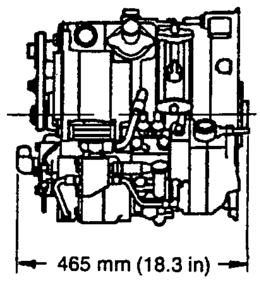
THE SCORE 70 SERIES FAMILY OF ENGINES

ROTARY ENGINE DIMENSIONS:

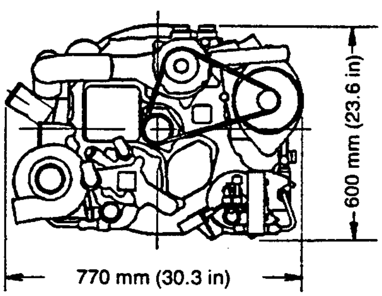
Envelope only, for vehicular applications. (Two-rotor version shown on front page) Dimensions for aircraft and generator set applications are available upon request.

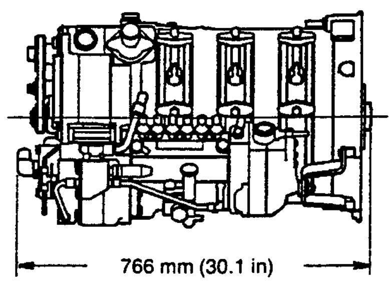
MODEL 1007R



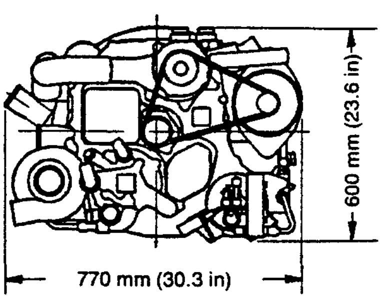


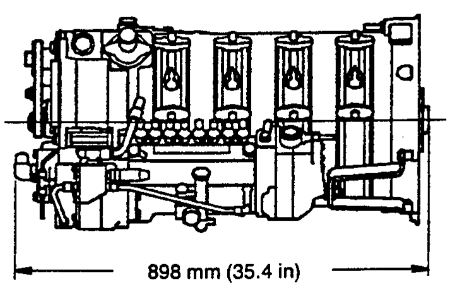
MODEL 3020R





MODEL 4026R





SCORE 70 SERIES PERFORMANCE AND BRIEF SPECIFICATIONS:

Model No.	Number of Rotors	Displacement L (in.³)	Power kW (BHP)	Growth[1] Rating kW (BHP)	Volume m^3 (ft.³)	Weight kg (lb.)	Specific Weight[2] kg/kW	Specific Weight[2] lbs/hp
1007R	1	.7 (40)	60 (80)	120 (160)	0.151 (5.32)	123 (270)	2.05	3.38
2013R	2	1.3 (80)	120 (160)	240 (320)	0.257 (9.08)	147 (325)	1.23	2.03
3020R	3	2.0 (120)	180 (240)	360 (480)	0.353 (12.46)	200 (440)	1.11	1.83
4026R	4	2.6 (160)	240 (320)	480 (640)	0.415 (14.65)	240 (530)	1.00	1.66

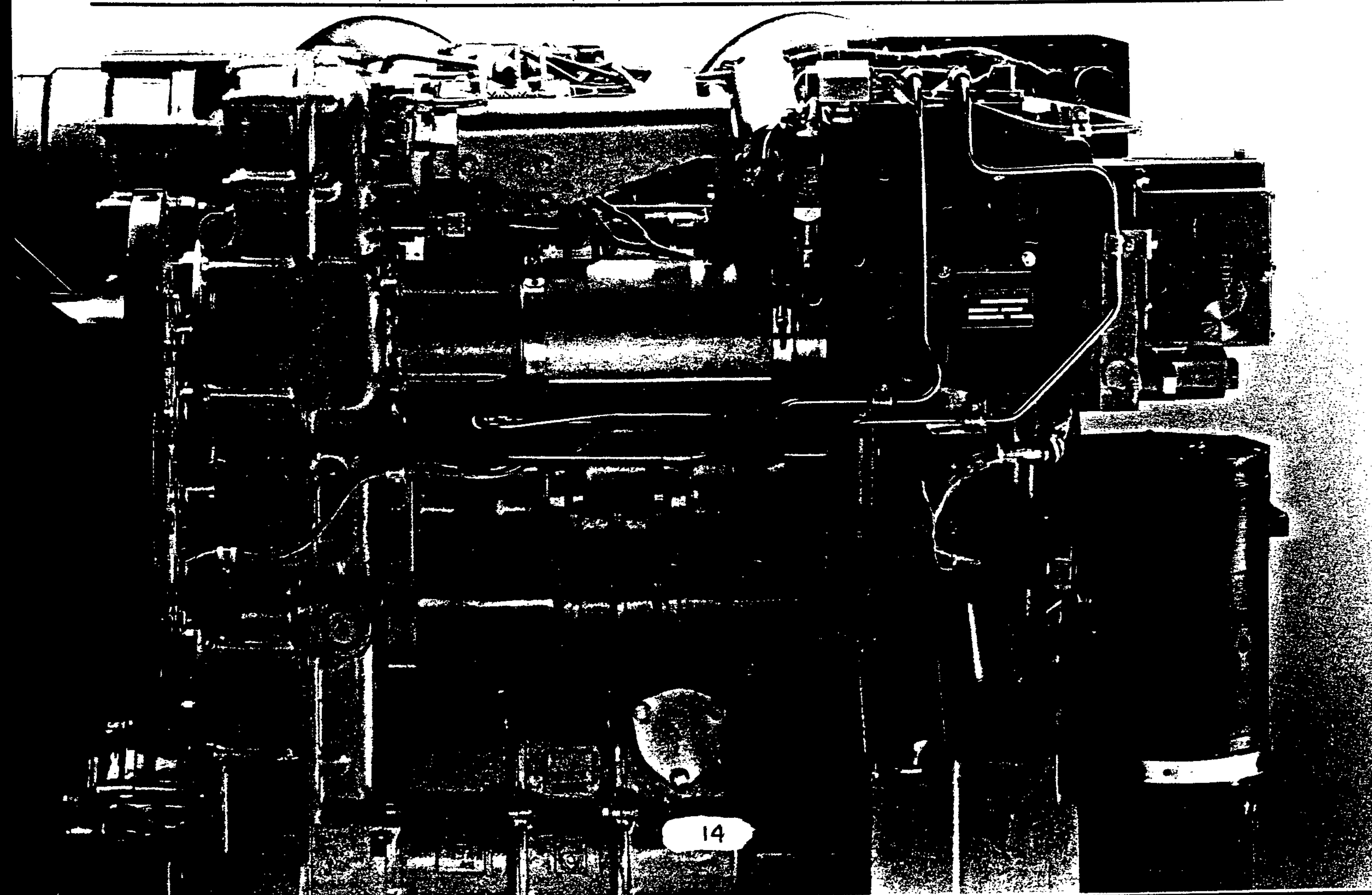
Notes: [1]Power growth version availability estimated for 1995 and beyond.
[2]Values are for the near-term power. For growth versions, specific values will be one-half.

For more information about RPI SCORE rotary engines call 201/470-7004, or write Advanced Programs, Rotary Power International Inc., Box 128, Wood-Ridge, New Jersey 07075.

All specifications are subject to change without notice.

eup of rotary engines

Series	Model	No. of Rotors	Power kW (bhp)	Displacement L (in³)	Height mm (in.)	Width mm (in.)	Length mm (in.)	Weight kg (lb.)
70 Series	1007R	1	60 (80)	.7 (40)	500 (19.7)	648 (25.5)	465 (18.3)	123 (270)
	2013R	2	120 (160)	1.3 (80)	546 (21.5)	744 (29.3)	633 (24.9)	147 (325)
	3020R	3	180 (240)	2.0 (120)	600 (23.6)	770 (30.3)	766 (30.1)	200 (440)
	4026R	4	240 (320)	2.6 (160)	600 (23.6)	770 (30.3)	898 (35.4)	240 (530)
170 Series	1017R	1	150 (200)	1.7 (105)	610 (24.0)	762 (30.0)	699 (27.5)	220 (485)
	2034R	2	300 (400)	3.4 (210)	610 (24.0)	762 (30.0)	874 (34.4)	280 (617)
	3051R	3	450 (600)	5.1 (315)	610 (24.0)	812 (32.0)	1050 (41.3)	350 (772)
	4068R	4	600 (800)	6.8 (420)	610 (24.0)	812 (32.0)	1250 (49.2)	435 (959)
	6102R	6	900 (1200)	10.2 (630)	610 (24.0)	812 (32.0)	1625 (64.0)	575 (1268)
580 Series	1058R	1	280 (375)	5.8 (350)	848 (33.4)	1043 (41.0)	859 (33.8)	580 (1279)
	2116R	2	560 (750)	11.6 (700)	848 (33.4)	1043 (41.0)	1107 (43.6)	771 (1700)
	3174R	3	840 (1125)	17.4 (1050)	848 (33.4)	1134 (44.7)	1348 (53.1)	1048 (2310)
	4231R	4	1120 (1500)	23.1 (1400)	848 (33.4)	1134 (44.7)	1590 (62.6)	1234 (2720)
	5290R	5	1400 (1875)	29.0 (1750)	889 (35.0)	1194 (47.0)	1831 (72.1)	1511 (3331)
	6347R	6	1680 (2250)	34.7 (2100)	889 (35.0)	1194 (47.0)	2073 (81.6)	1633 (3600)



Gas turbine engines with gearbox reducers have a weight to HP ratio of **0.5-1 lbs/HP** compared to the weight to HP ratio for the diesel engines that is **from 6-8 lbs/HP** (for a few hundred HP diesels) to **9-10 lbs/HP** (for small diesel engines with HP less than 100 HP) [7].

The gearbox reducers are required because of the very high speeds of the turbine shafts that are over 100,000 RPM for small engines in the power range from 12 HP to 60 HP, about 40-60,000 RPM for engines in the power range from 90 HP to 350 HP, and about 18-22,000 RPM for engines in the power range from to 350 HP to 4,000 HP.

Regenerative gas turbine engines with an output power of more than 300 HP can be comparable to diesel engines in fuel economy [8].

On Figure 2, page 16, 395 HP and 450 HP Ford marine gas turbine engines with gearbox reducers are shown [9]. The first gas turbine engine is suitable for a 230 kW generator set that will have a total weight of approximately 2,900 lbs. compared to the total weight of the 230 kW diesel generator set that is approximately 6,050 lbs., or **twice lighter!**

If these engines will be used with high speed alternators with direct coupling with turbine shaft, their weight can be significantly reduced because of the elimination of gearboxes.

These engines have a S.F.C. of about **0.440 lbs/HP·hr** including losses in their gearboxes compared to **0.375 lbs/HP·hr** for diesel engines of the same power. Their S.F.C. is only 14% higher, and this difference could be insignificant if we take into consideration the requirement of the high level of mobility equal to the mobility of the US Air Force.

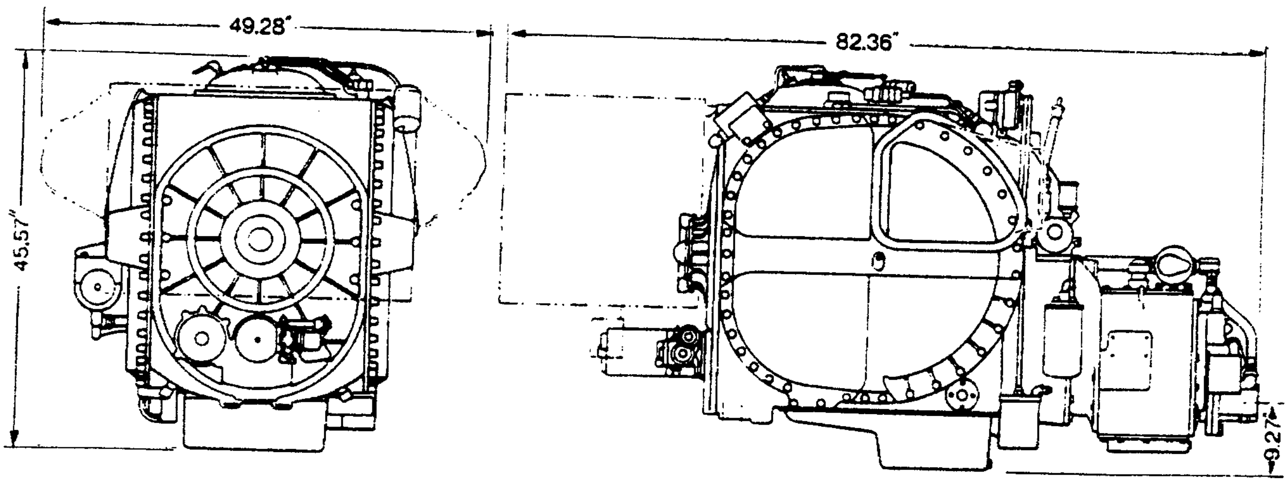
The production cost of the turbine engines might be less than the cost of production of the conventional gasoline engines in comparative quantities [10]. General Motors, Ford, Chrysler, and other car manufacturers have a full line of the turbine engines that were designed for automotive applications.

The current very high price of military grade turbine engines can be explained by the fact that these engines are manufactured in very small quantities (from a few units to a few dozen). Quantities of a few hundred units are very rare.

In Table 3 on page 17 the engine and alternator speeds for gas turbine engine gen-sets from 15 HP to 10,000 HP are shown.

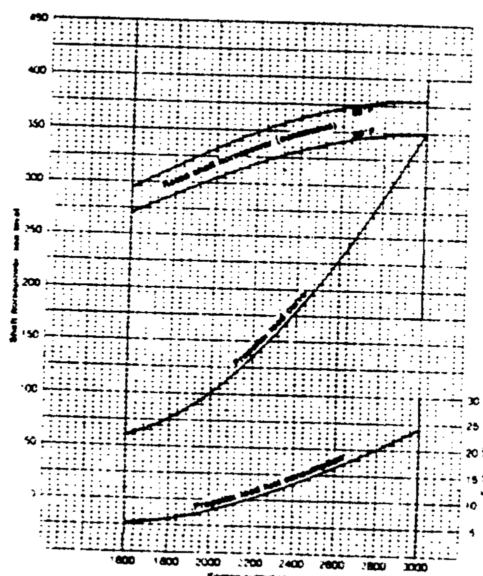
For the illustration of all the advantages of implementation of the HFA-PFC Technology in gen-sets with gas turbine engines, lets compare existing conventional military 60 kW, 400 Hz gas turbine gen-set type MEP with proposed gas turbine engine gen-set based on the HFA-PFC Technology.

COMPACT SIZE MAKES INSTALLATION EASY.

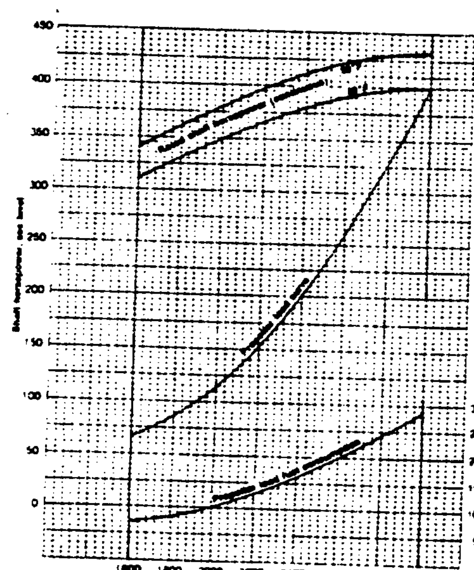


Basic dimensions for the Ford marine turbine, equipped with Twin Disc gearbox. Intake plenum and exhaust connections are indicated by dashed lines. Weight, as equipped, is 2,780 pounds.

FORD TURBINE PERFORMANCE FOR MARINE APPLICATIONS.



Performance curves, Ford 360M-2000-A engine.



Performance curves, Ford 420M-2000-A engine.

Figure 2. Ford gas turbine engine

Table 3.

Engine Model	HP	Engine speed, RPM	Alternator speed/ Frequency, RPM/ Hz	Frequency, Hz direct coupling, 2-pole exciter
"Gemini"	24	105,000	6,000/400	2,000
"Titan"	90	61,000	6,000/400	1,000
	125	60,000	6,000/400	1,000
	350	40,000	3,600/60	667
"Saturn"	1,200	22,300	3,600/60	371
"Centar"	4,000	18,000	3,600/60	300
"Mars"	10,000	8,700	1,800/60	145

The conventional gas turbine gen-set type MEP 404B has dimensions of L x W x H = 59 x 33 x 26 inches. [1,11,12].

The assembly of the engine, gearbox, and alternator for this gen-set is shown on Figure 3, page 18. This is a 90 HP gas turbine engine with a gear reducer pad, model TITAN T-62T-32, manufactured by the Solar Division of International Harvester Company, and equipped with 60 kW Alternator, model TG2G32A, manufactured by General Electric [1,12]. Gearboxes are very expensive, about $30,000, and require frequent replacements if they are used for continuous operations.

The weight of the engine, reducer, and alternator only without the frame and auxiliary equipment is 222 lbs.

The described 60 kW gas turbine generator set was manufactured for the Department of Defense by Libby Welding Company, Kansas City, Missouri in recent years. This generator set was developed for the US Air Force by the Solar Turbines International, Inc., San Diego, California [12].

On Figure 4, page 18, the assembly of engine and alternator in the direct drive version is shown. In this case, the expensive and heavy gearbox is eliminated.

The 90 HP (67 kW) gas turbine engine model TITAN T-62T-32 without a gearbox has dimensions of L x W x H = 17.4 x 16 x 16 inches and a weight of 71 lbs [2].

Only the elimination of the gearbox will reduce the weight of gen-set by 151 lbs, space by 4,454 cu. In., and cost by $30,000.

This could be achieved only if a 60 kW, 60,000 RPM high speed alternator will be used.

For discussion about high speed alternators see pages from 24 to 36. Now we want only to mention that these alternators could be built using special design innovations developed by JSP Industries, Inc.

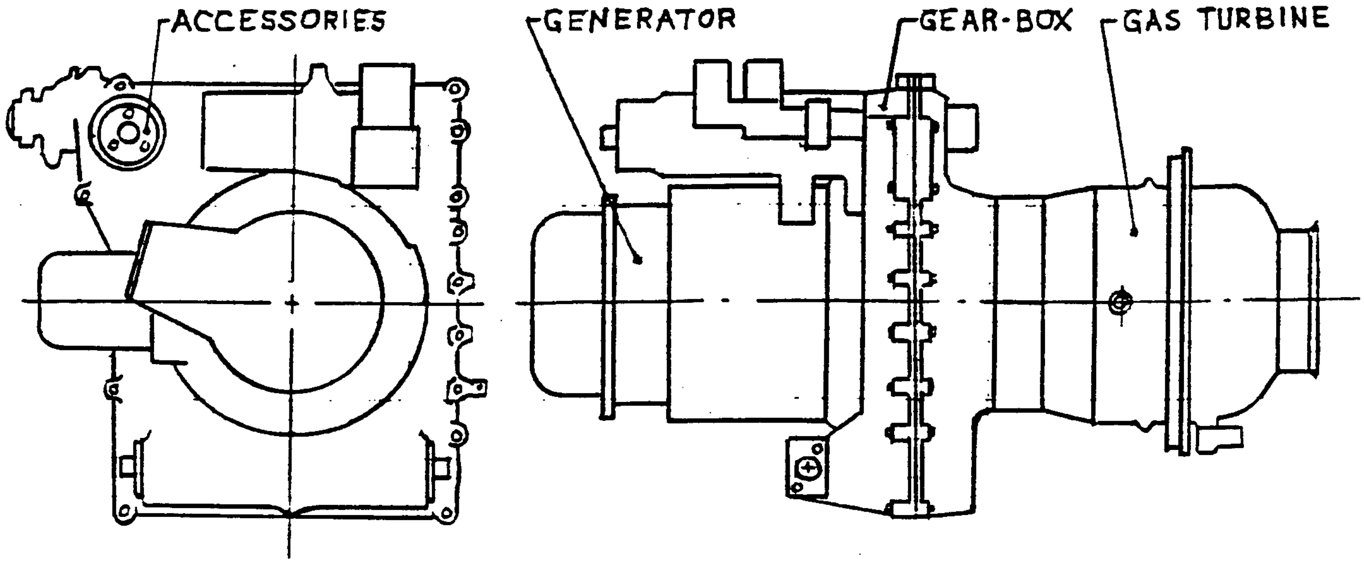


Figure 3 . Conventional 60 kW military gas turbine engine gen-set

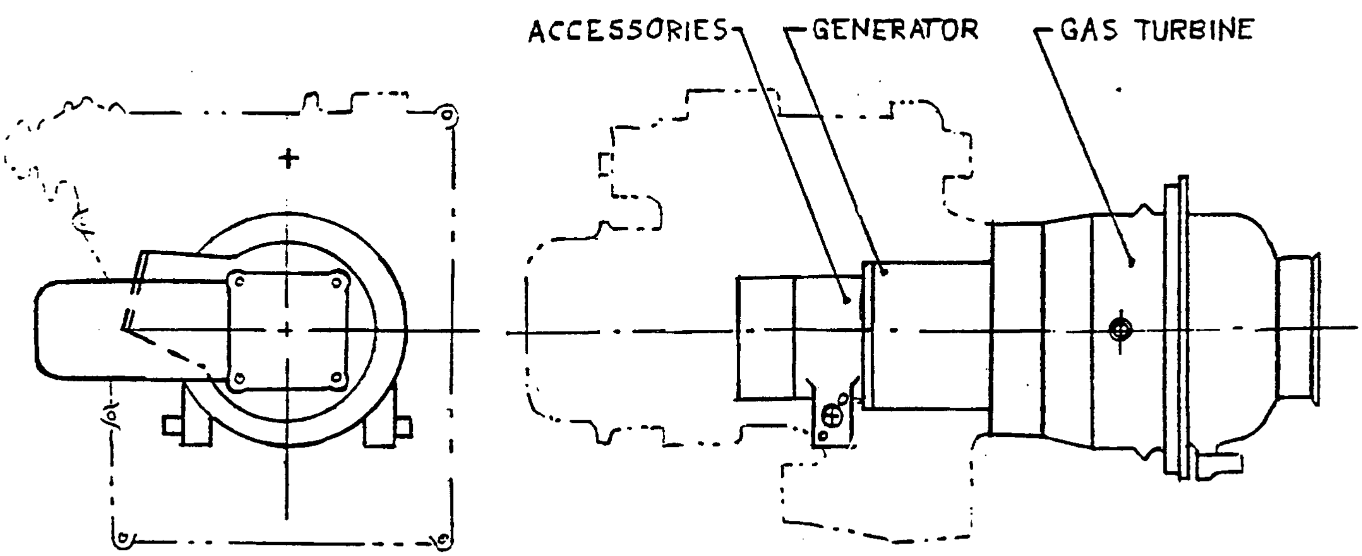


Figure 4. Direct drive 60 kW military gas turbine engine gen-set

Conclusion: For the short term planning (2-5 years), the existing TQGs could be replaced only by improved gen-sets using existing diesel engines if the fuel economy is the main requirement.

However, other types of engines, rotary and gas turbine, should be taken in consideration for the long term planning (5-10 years) because intensive research and development (R & D) programs conducted by Rotary Power International, Inc. for improvement of the rotary engines under contracts with the Department of Defense and R & D programs conducted by the Allison Engine Company for improvement of the gas turbine engines under contracts with the Department of Energy, NASA, and General Motors Corp. exist.

The Ford Company has similar R & D programs for improvement of the gas turbine engines under contracts with the Department of Energy and NASA.

The targets of all the mentioned programs are rotary or gas turbine engines with S.F.C. and price equivalent to S.F.C. and price of the diesel engines.

However, even in the case of complete success, the rotary engines from Rotary Power International, Inc. will have minimum S.F.C. of 0.450 lbs/HP·hr compared to 0.375 lbs/HP·hr for the existing diesels, or 20% higher. The estimated production price of the rotary engines will be in the range of $12-14,000 each for small engines.

The ceramic gas turbine engines from Allison Engine Company, in the case of complete success, will have S.F.C. and price equivalent to existing gasoline car engines. This very limited information was provided by Mr. Duge, Deputy Program Manager for Allison Engine Company. Mr. Duge declined to disclose the exact S.F.C., turbine shaft speed, and other technical information about their ceramic gas turbines as company confidential information.

All mentioned R & D programs are long term programs with multi-million dollar budgets. The expected production is scheduled not earlier than the end of this decade.

In the near term, only diesel engines will be available as field tested engines with strong positive information about their reliability and low fuel consumption.

However, only gen-sets with gas turbine engines are a promising solution if size and weight are the main requirements, and there is a very strong reason to build a prototype utilizing existing gas turbine engine for demonstration of all the advantages of High Frequency Alternator, Power Frequency Conversion (HFA-PFC) Technology for Lightweight Tactical Power Generation.

Alternators

Conventional alternators, in the conventional version with slip rings and brushes for exciter circuit, are not reliable enough for military applications, and they were replaced by brushless alternators.

The brushless AC alternator actually consists of two alternators on the common shaft. The main alternator generates the output AC current. A smaller alternator, the exciter, generates an AC current that, after rectification, is used for exciter of the main alternator.

Conventional brushless alternators have rotor speeds of up to 6,000 RPM. At speeds above 6,000 RPM centrifugal forces might lead to the displacement of the rotor armature, disbalance of the rotor masses, increase of vibrations, and finally, damages to the alternator.

An exploded view of a conventional military brushless AC alternator is shown on Figure 5, page 21. This is a 10 kW, four-pole 60 Hz alternator for direct drive from a diesel engine at 1,800 RPM [18]. An exploded view of the rotor of this alternator is shown on Figure 6, page 22.

The 10 kW, 400 Hz military alternator has the same design concept, and the only difference is in the number of the rotor magnetic poles. An exploded view of the rotor of this alternator is shown on Figure 7, page 23.

The alternator model TG2G32A manufactured by General Electric and used in the 60 kW gas turbine engine gen-set MEP-404B has the same design concept.
This alternator has output power of 60 kW, 400 Hz at 6,000 RPM.

If the conventional four-pole alternator of the diesel gen-set that has the output voltage and frequency of 120 VAC, 60 Hz at 1,800 RPM will be used in variable shaft speed mode with shaft speeds in the range of 600 RPM to 3,600 RPM, the output voltage and frequency will be about 40 VAC, 20 Hz at 600 RPM that is too low, and 240 VAC, 120 Hz at 3,600 RPM that is too high.
If the output voltage could be regulated by a voltage regulator, the frequency can't be regulated. This is why the shaft speed of conventional alternators should be constant.

High Frequency, Low Speed Alternators for diesel engine gen-sets with variable shaft speeds from 600 to 3,600 RPM (HFA-PFC Technology) and direct coupling of the alternator with the engine can have the conventional design as shown on Figure 5, page 21 and Figure 6, page 22, but with a higher number of poles.
The 12-pole (6 pairs of poles) main exciter will generate current with frequency from 60 Hz at 600 RPM to 360 Hz at 3,600 RPM.

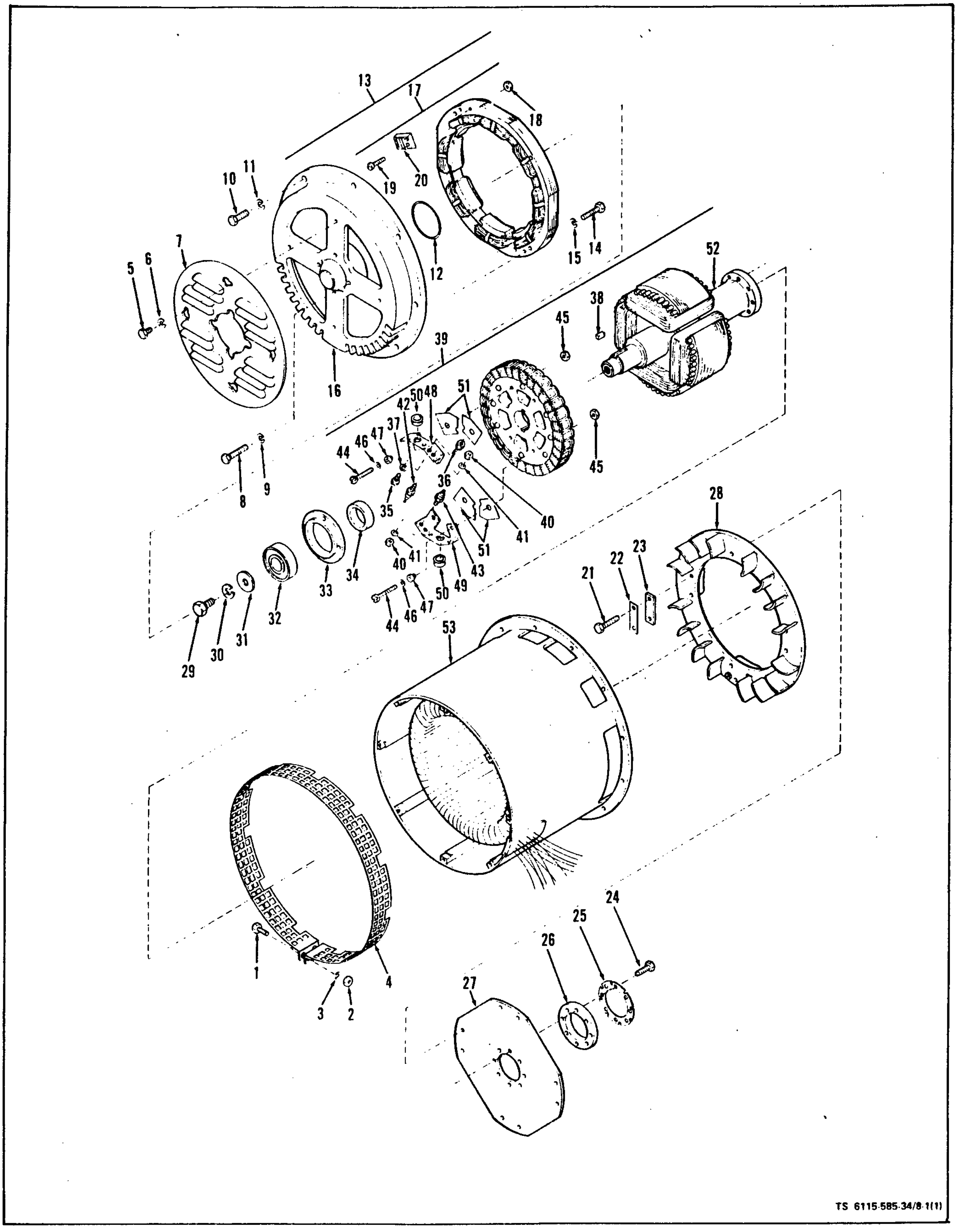


Figure 5. Exploded view of conventional 1,800 RPM alternator for military gen-set

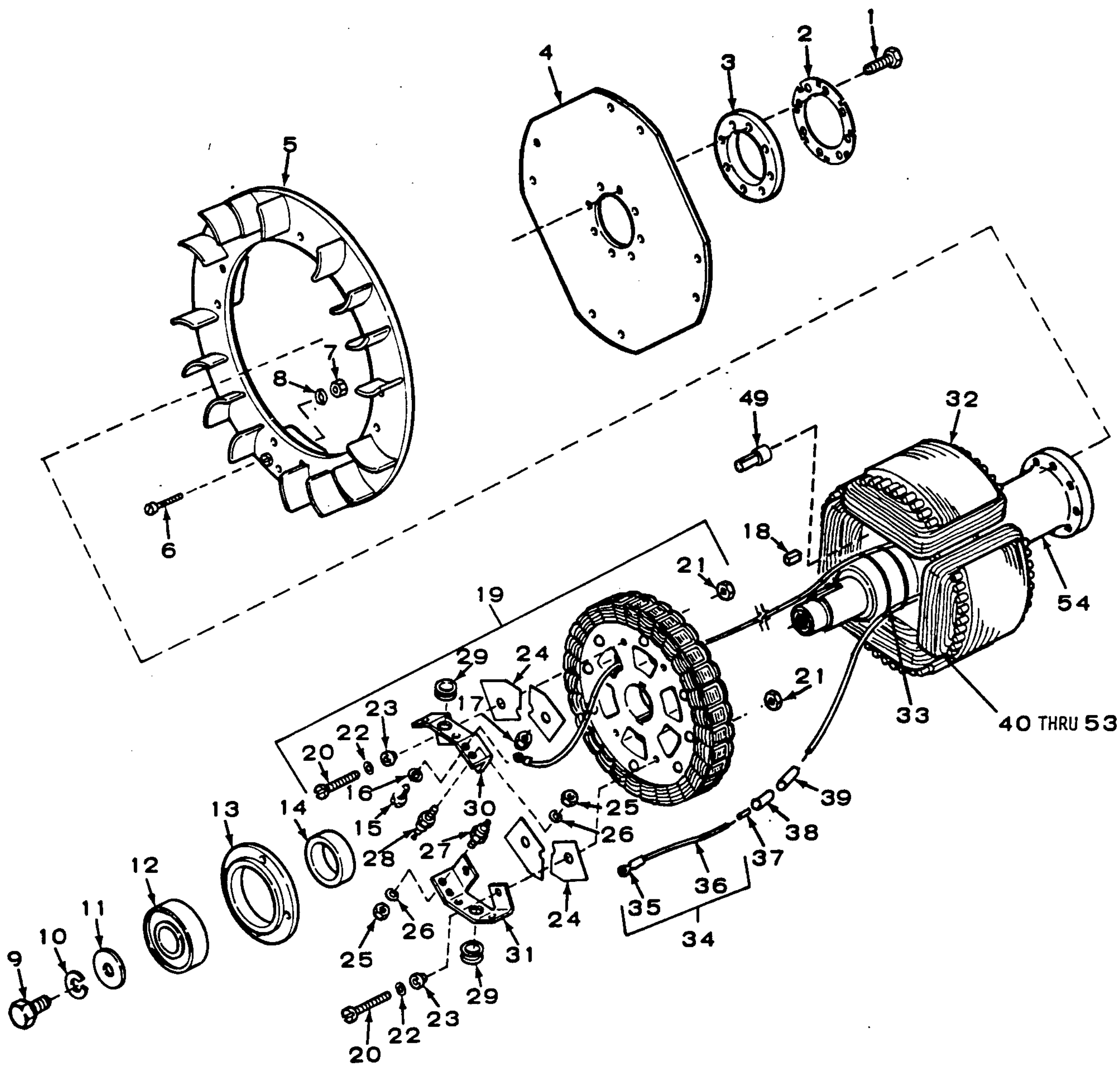


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FIGURE 6. Rotor assembly—exploded view

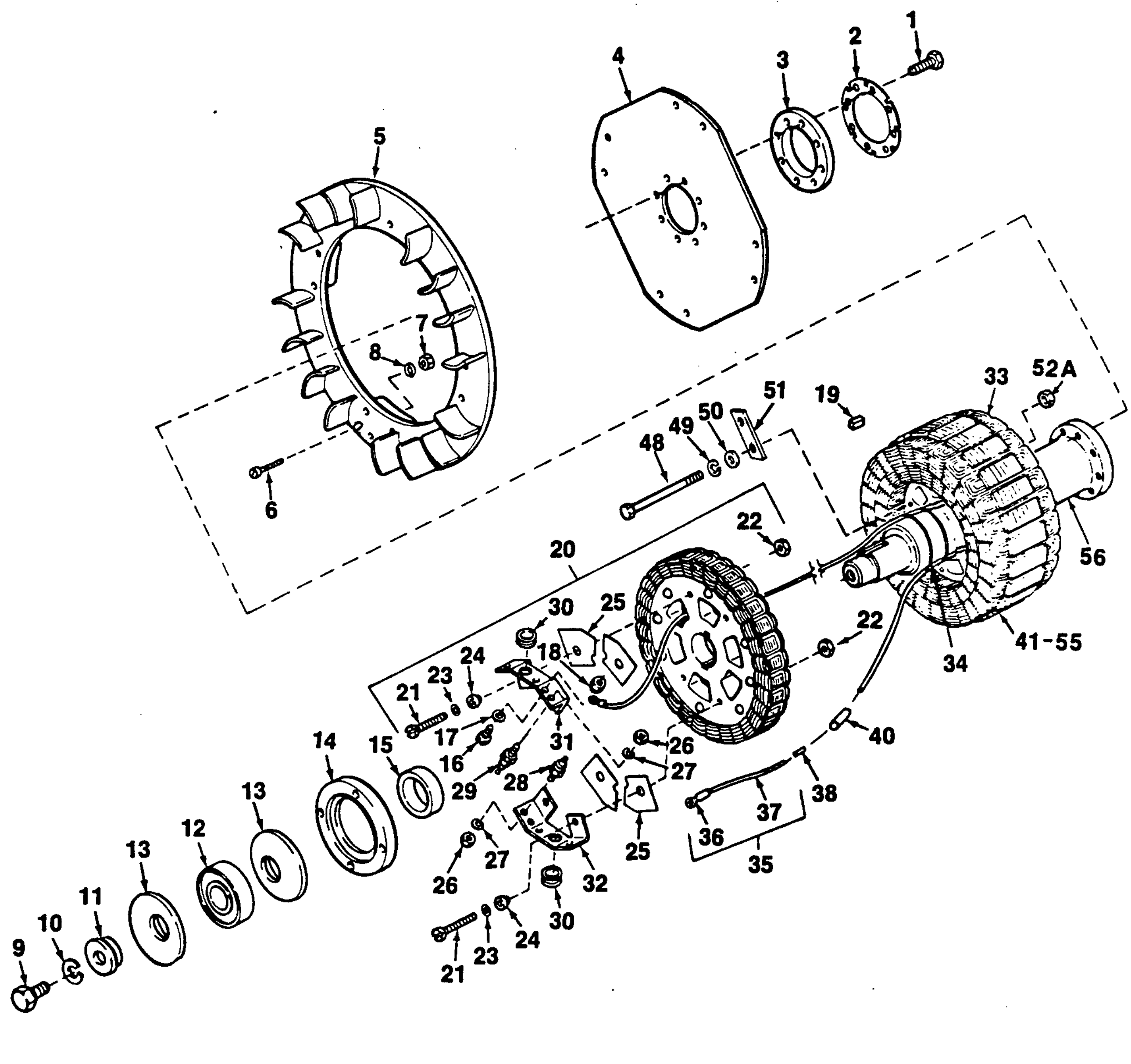

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FIGURE 7. Rotor assembly - exploded view

The 60-pole exciter will generate a current with a frequency from 300 Hz at 600 RPM to 1,800 Hz at 3,600 RPM, etc. However, the multi-pole exciters with a high number of poles will cause some difficulties in design, and twelve pairs is usually the maximum number of exciter poles.

The size and weight of the described high frequency alternator for a 10 kW gen-set with variable shaft speeds from 600 RPM to 3,600 RPM and direct coupling with the diesel engine would be the same as existing 10 kW alternators or more. The power frequency conversion unit will add an additional increase in the size and weight that means that this concept is unpractical.

Many types of high frequency generators exist that have low shaft speed. One of them is shown on Figure 8, page 25. However, all of them are larger and heavier than conventional alternators used in the existing gen-sets.

High Frequency, High Speed Alternators. The HFA-PFC Technology can be implemented in diesel gen-sets only if the high frequency, high speed alternators will be used. In this case, the size and weight of the high speed alternators will be in inverse proportion to their speed. To get all the advantages of this concept, a gearbox multiplier should be installed between the engine and alternator as shown on Figure 1, page 10

In this case, the size and weight of the high speed, high frequency alternator, including gearbox, could be much smaller compared to the conventional alternator of the same power at 1,800 RPM.

The gearbox multiplier that is shown on Figure 1, page 10 has an output shaft speed of 12,600 RPM at a rated power of **10 kW** (engine crankshaft speed of 1,800 RPM) and speed of 25,200 RPM at a maximum power of **18.2 kW** (engine crankshaft speed of 3,600 RPM).

This means that the alternator should be designed for 18.2 kW continuous output power at 25,200 RPM, and conventional brushless alternators couldn't be used for this application.

At speeds above 6,000 RPM centrifugal forces might lead to the destruction of the rotor armature.

From all existing high speed alternators, the most promising are permanent magnet (PM) alternators and wound-rotor, variable speed alternators.

Both of these machines are commonly used as electric motors at comparatively low speeds, under 6,000 RPM.

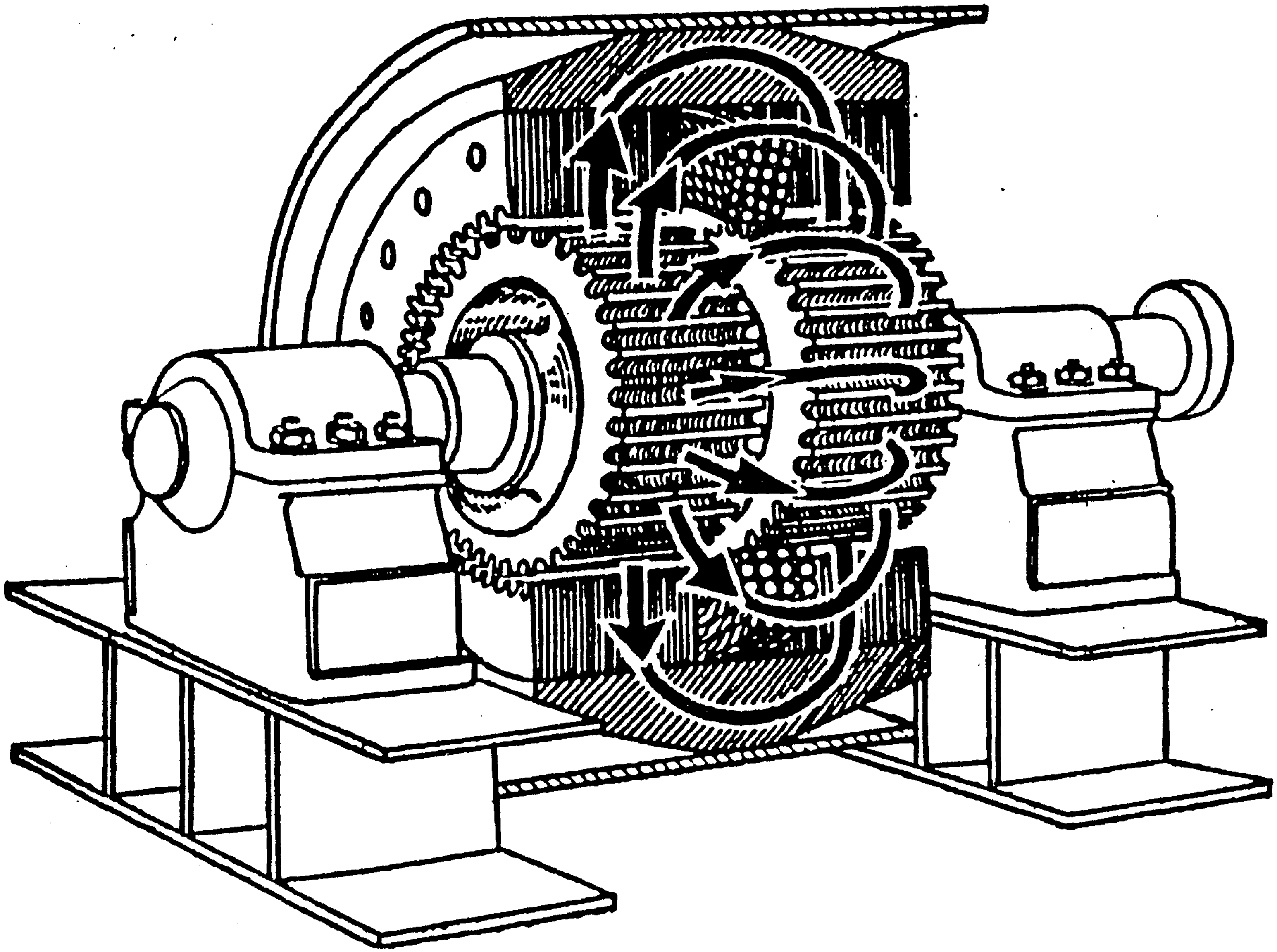


Figure 8. High frequency, low shaft speed generator.

Permanent Magnet (PM) Alternators actually are conventional brushless DC motors used as generators. In this case, the rotor position sensors and switching power supplies are not required. The rotating magnetic field of the rotor permanent magnets generates a 3-phase AC current in the conventional 3-phase stator winding.

PM alternators don't have any means for output voltage regulation at a fixed rotor speed. The output voltage and frequency could be hardly regulated by change of the rotor speed: increase in speed will proportionally increase the frequency and voltage. The output voltage will also depend on a value and kind of load, active or reactive, while the frequency will depend on the shaft speed only.

Conventional permanent magnet (PM) alternators can have power up to 30 kW at speeds up to 3,000 RPM. Smaller alternators have higher speeds.

The usage of bandages might increase the operational speeds up to 60-80,000 RPM. However, all known high speed alternators with bandage devices generate less power and have increased losses compared to conventional devices.

High frequency, high speed alternators for diesel gen-sets based on the HFA-PFC Technology could have speeds up to 20-25,000 RPM. Practically, this limit should be reduced to 12-15,000 RPM because of the utilization of the gearbox speed multipliers and mechanical problems with bearings, rotor balancing, vibrations, noise, heat dissipation, etc.

High speed alternators in the speed range from 20,000 RPM to 120,000 RPM are required for gen-sets with gas turbine engines based on the HFA-PFC Technology in the version without a gearbox reducer between the engine and alternator.

In this case, the problem is that all existing small gas turbine engines have very high turbine rotor speeds to have acceptable specific fuel efficiency.

Some engineering improvements of existing small gas turbine engines developed by JSP Industries, Inc. have been separately proposed.

These improvements were proposed to reduce turbine shaft speeds without compromise in specific fuel efficiency.

However, development of any kind of engines for the HFA-PFC Technology gen-sets wasn't included neither in the Phase I effort, nor the Phase II effort, and we should plan the Phase II effort using only existing engines or engines that are under development by third parties under contracts with the Department of Defense, the Department of Energy, NASA, etc.

Conventional high speed ball bearings could be used at speeds up to 60,000 RPM. This kind of bearings is used in small gas turbine engines. However, the size and weight of the rotor of a matching alternator of the same power and speed is much higher than to the shaft of gas turbine, and special high speed bearings should be used.

From the mechanical point of view, high speed PM alternators are the same as high speed induction motors.

Significant progress was achieved in the development of the high speed electrical motors with a wireless rotor design concept (squirrel cage or solid rotor) [13,15].

This experience can be used for the development of PM alternators.

The stators of both machines can have the same type of windings, and the difference is mostly in the rotor design.

An electrical motors with power range of 50 kW to 200 kW at 28,500 RPM was built by Westinghouse Electric Corporation. This motor is shown on Figure 9, page 28.[15].

An electrical motor with a power of 40 kW at 30,000 RPM was built by Missler. The same design concept was used for a product line of motors from .5 kW to 200 kW at 30,000 RPM and is shown on Figure 10, page 29.[13].

An electrical motor with a power of 30 kW at 60,000 RPM with a squirrel cage rotor was built by another manufacturer. The same design concept was used to build the 60 kW, 60,000 RPM motor.

A combination of special hydrostatic and hydrodynamic bearings was used in this design that is shown on Figure 11, page 29.[16].

The efficiency of these motors can be increased if ball or roller bearings will be used. However, if these type of bearings wouldn't be available for large size alternators, the hydrostatic and hydrodynamic bearings are available from FAG Bearings Corp., Stamford, Connecticut.

The hydrostatic and hydrodynamic bearings are used when powerful devices are used at high speeds. On Figure 12, page 30, a gearbox multiplicator for centrifugal pumps with powers up to 400 HP and speeds up to 20,000 RPM is shown. These gearboxes are manufactured by Ingersoll-Rand, Phillipsburg, New Jersey.

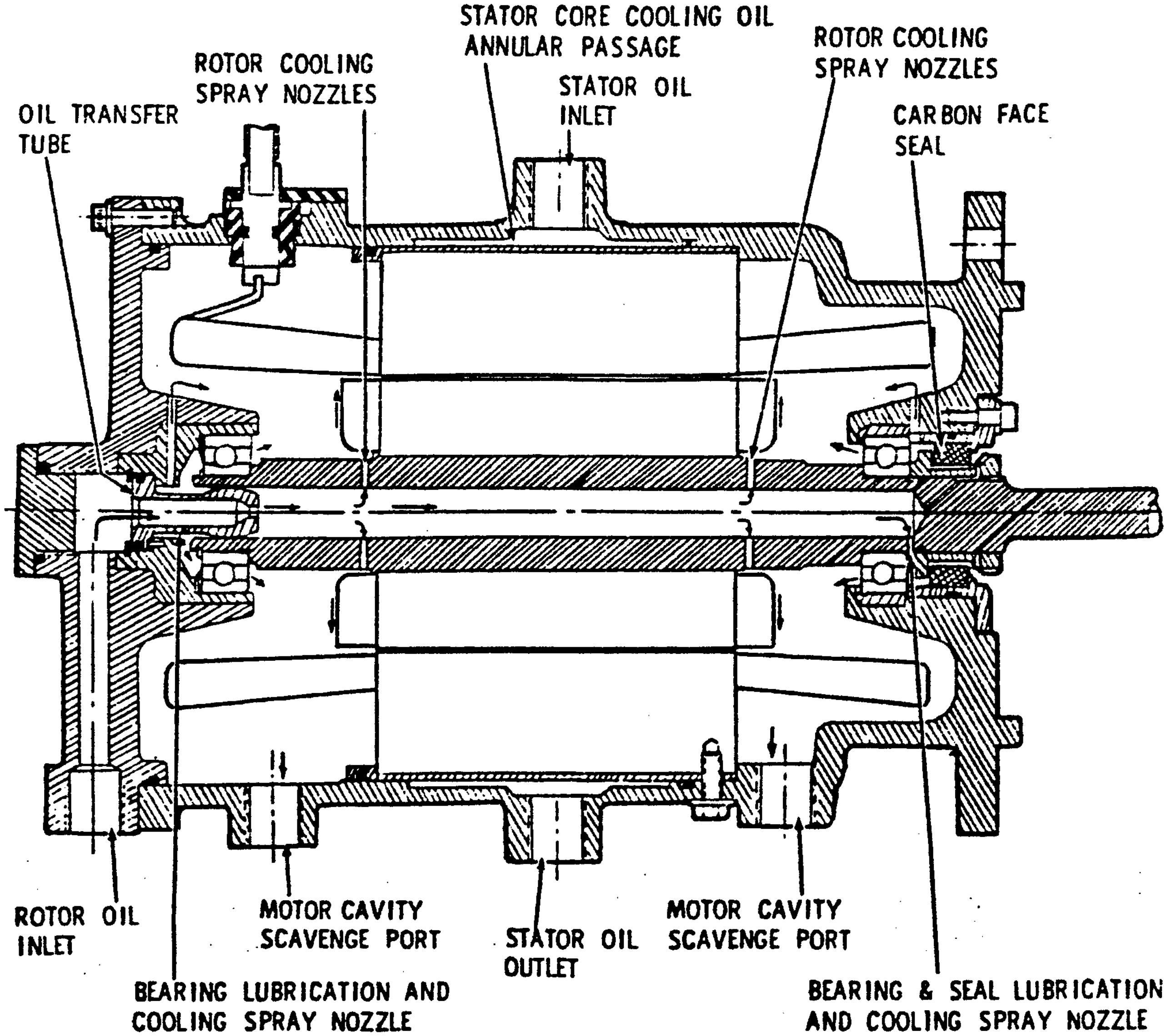


FIGURE 9. Typical spray oil-cooled motor cross section

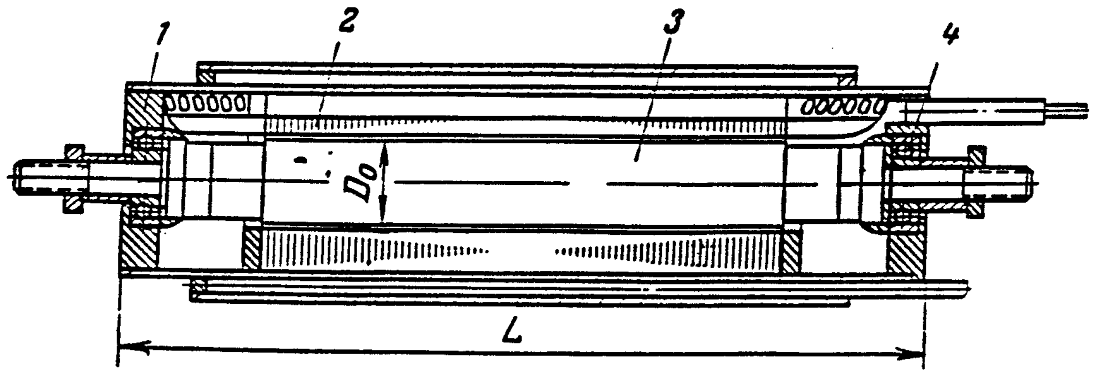


FIG. 10. 200 kW, 30,000 RPM Electrical Motor

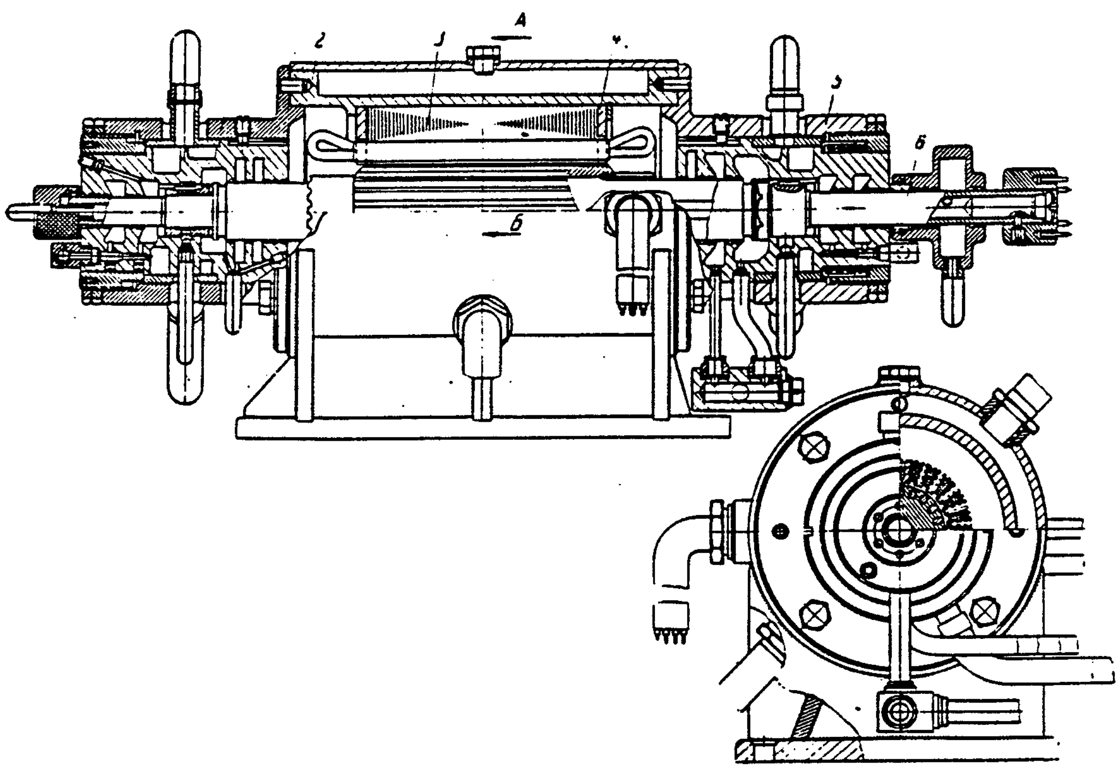


FIG. 11. 60 kW, 60,000 RPM Electrical Motor

Quiet, helical gearing

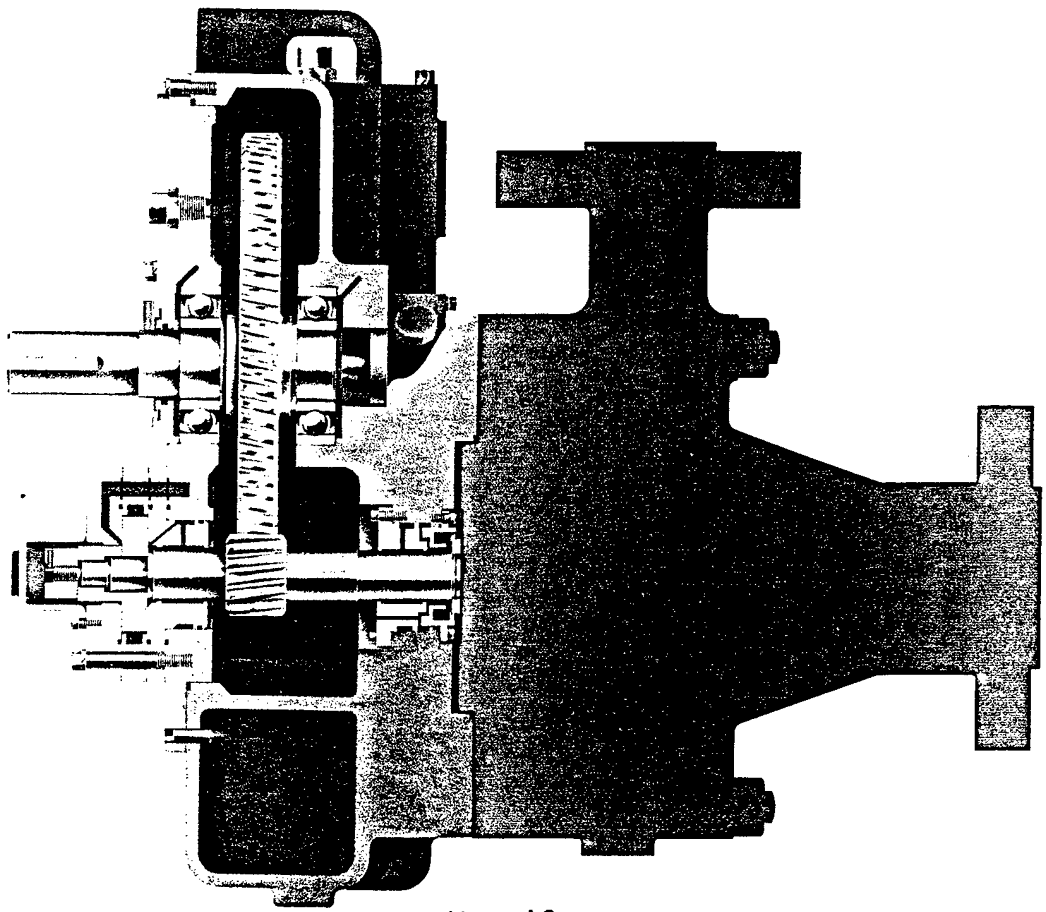


Fig. 12.

Sier-Bath, part of worldwide Ingersoll-Rand has brought its gear design expertise to the HSP, producing a durable, quiet, rugged gearbox.

A helical gear assembly was selected for smooth, quiet operation. All gears are carburized hardened and precision ground, designed to meet AGMA Class Eleven gear specifications. The HSP pinion gear is crown ground to insure central tooth loading. This feature protects vulnerable tooth ends, minimizes sensitivity to gear misalignment, and increases gear life. Gearboxes are mechanically run and completely tested prior to shipment.

Automatic pre-lube eliminates the "bumps"

Thanks to a unique gearbox design, bearings are automatically flooded prior to start-up, eliminating the need for "bump" starting before operation. After start-up, oil automatically moves to a retaining tank, increasing the oil reserve, and establishing the normal operating oil level. When unit shuts down, bearings automatically re-flood.

Some engineering improvements of existing high frequency, high speed PM alternators have been developed by JSP Industries, Inc.

The estimated maximum power of these alternators is about 30-50 kW at 60, 000 RPM.

In 1988 a patent search was performed by Litman, McMahon and Brown Patent Law Office, 1200 Main, suite 1600, Kansas City, MO 64105, for our concept of the High Speed Motor/Alternator. No similar patents were found.

In 1991 patent application was prepared by the same Patent Law Office.

We mentioned about these devices to confirm the feasibility to build the high speed alternators that will have speeds of 60,000 RPM and more and will have the required reliability for military and commercial applications.

Mechanical schematic of typical conventional gas turbine engines with power over 500 HP and their gearbox reducers are shown on Figure 13a, page 32, and on Figure 13b, page 33 respectively.

An exploded view of the gearbox reducers that are used in gas turbine gen-set MEP-404B is shown on Figure 14, pages 34 and 35.

The next major step in gen-set technology can be done if the high speed alternators with rotor speeds of 60-90,000 RPM will be developed. Expensive gearbox reducers will become unnecessary because these alternators could be coupled directly with the shaft of the gas turbine engine.

Utilization of the reliable electric alternators with direct coupling to the shaft of the turbine engine will eliminate gear box reducers that will reduce size, weight, cost, and will increase reliability of the system.

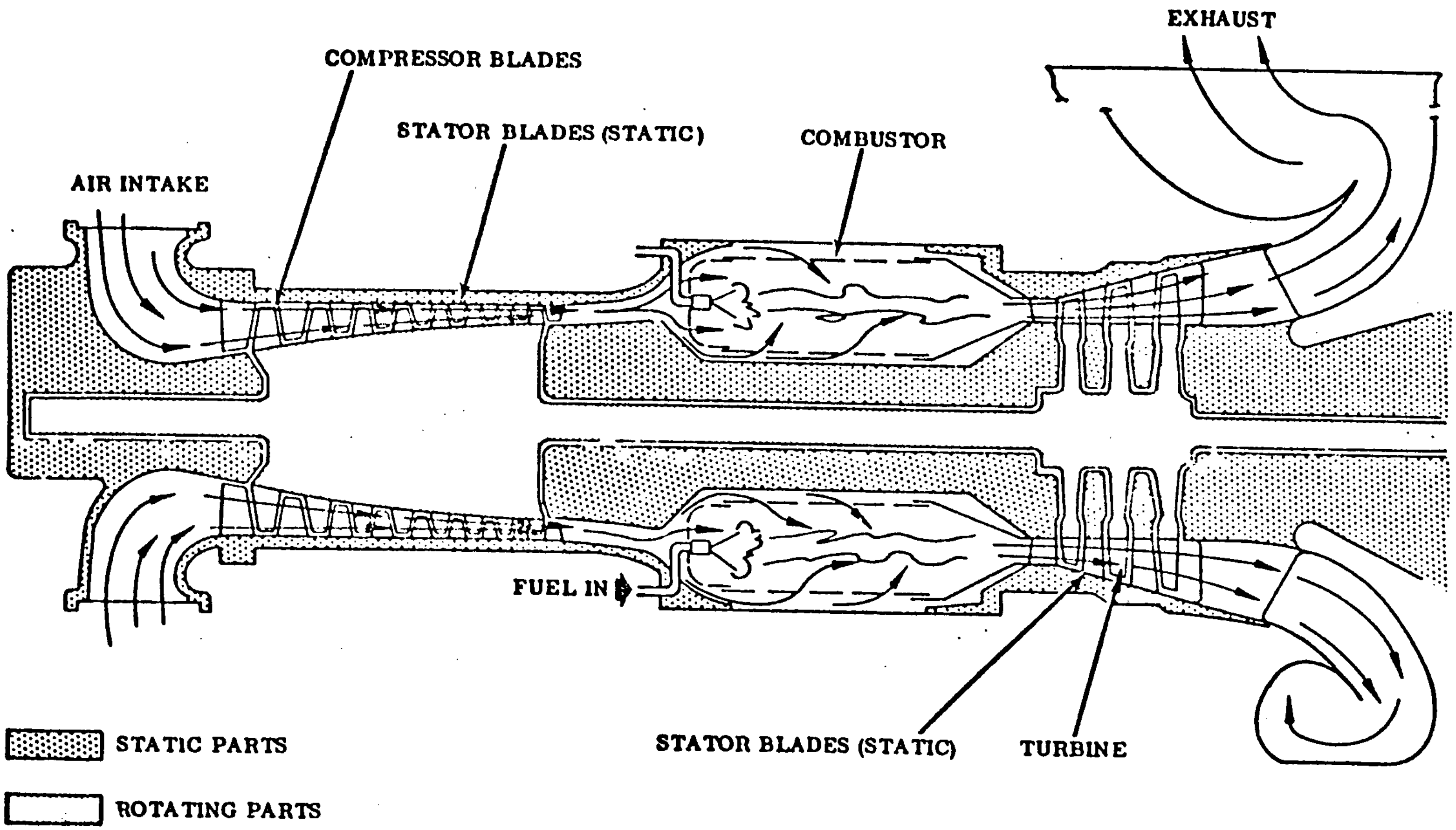


Figure 13a. Simplified Airflow Diagram

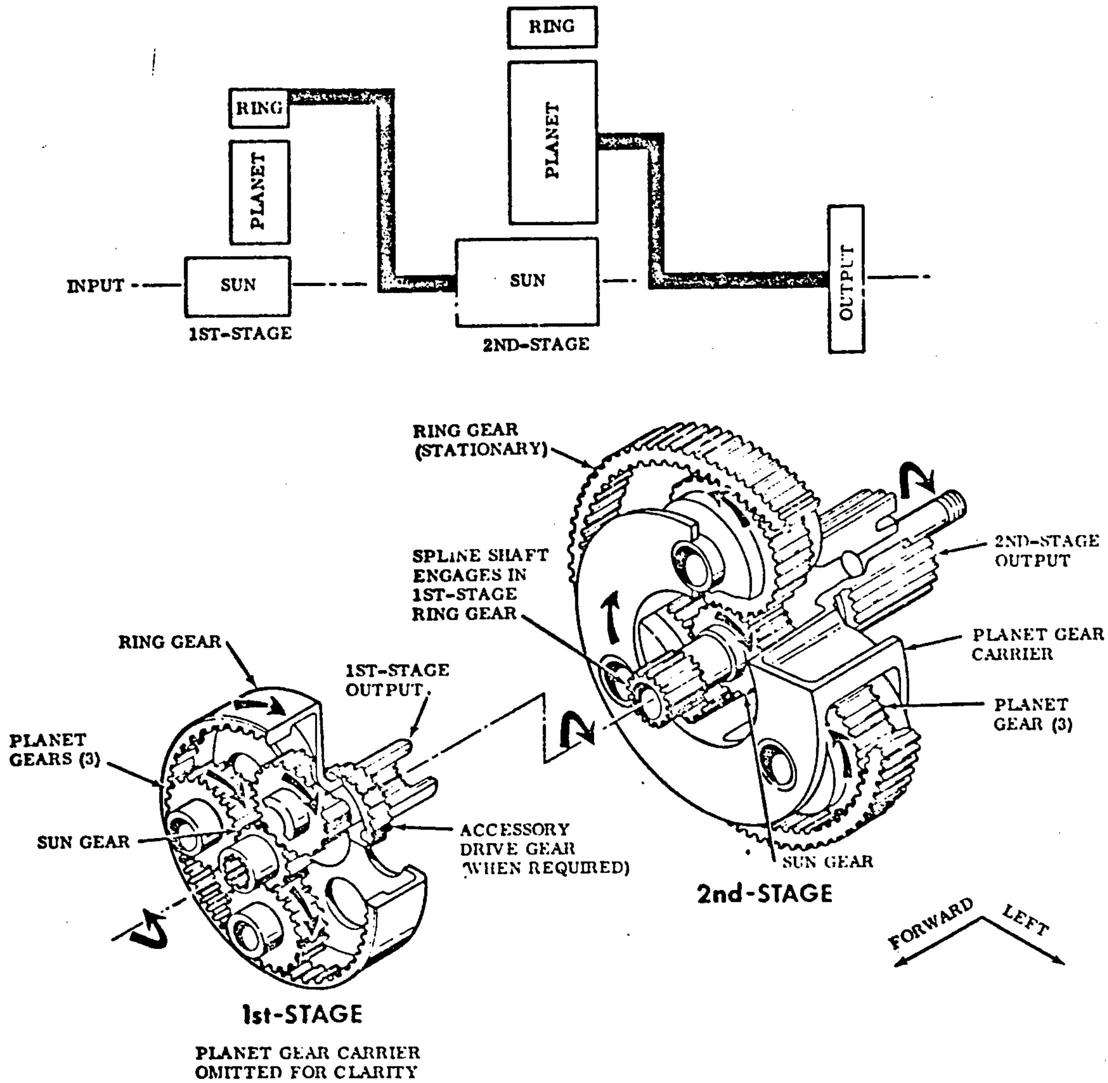


Figure 13b. Reduction Drive Gear Arrangement

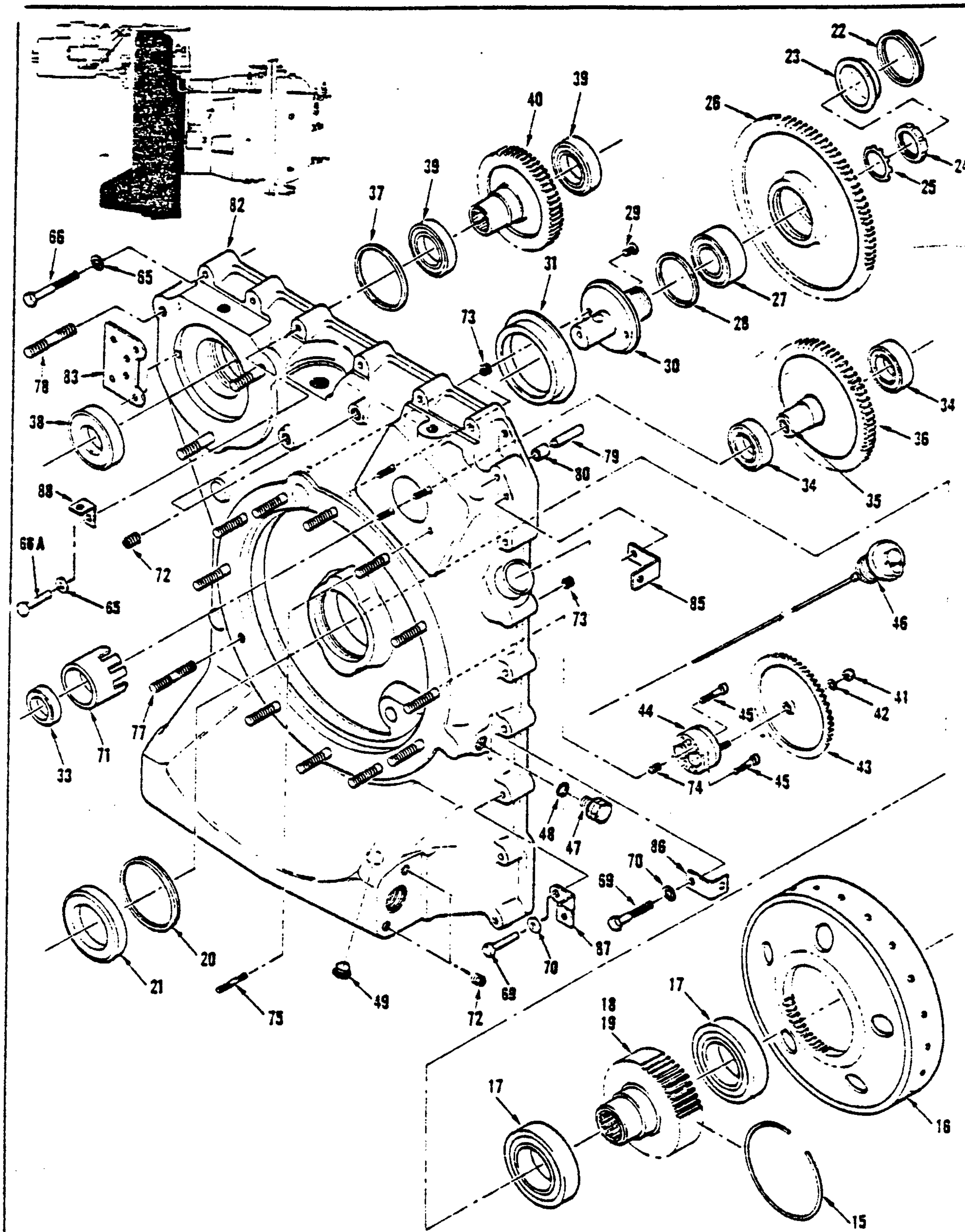


Figure 14. Gear Reduction and Accessory Drive Assembly (Sheet 1 of 2)

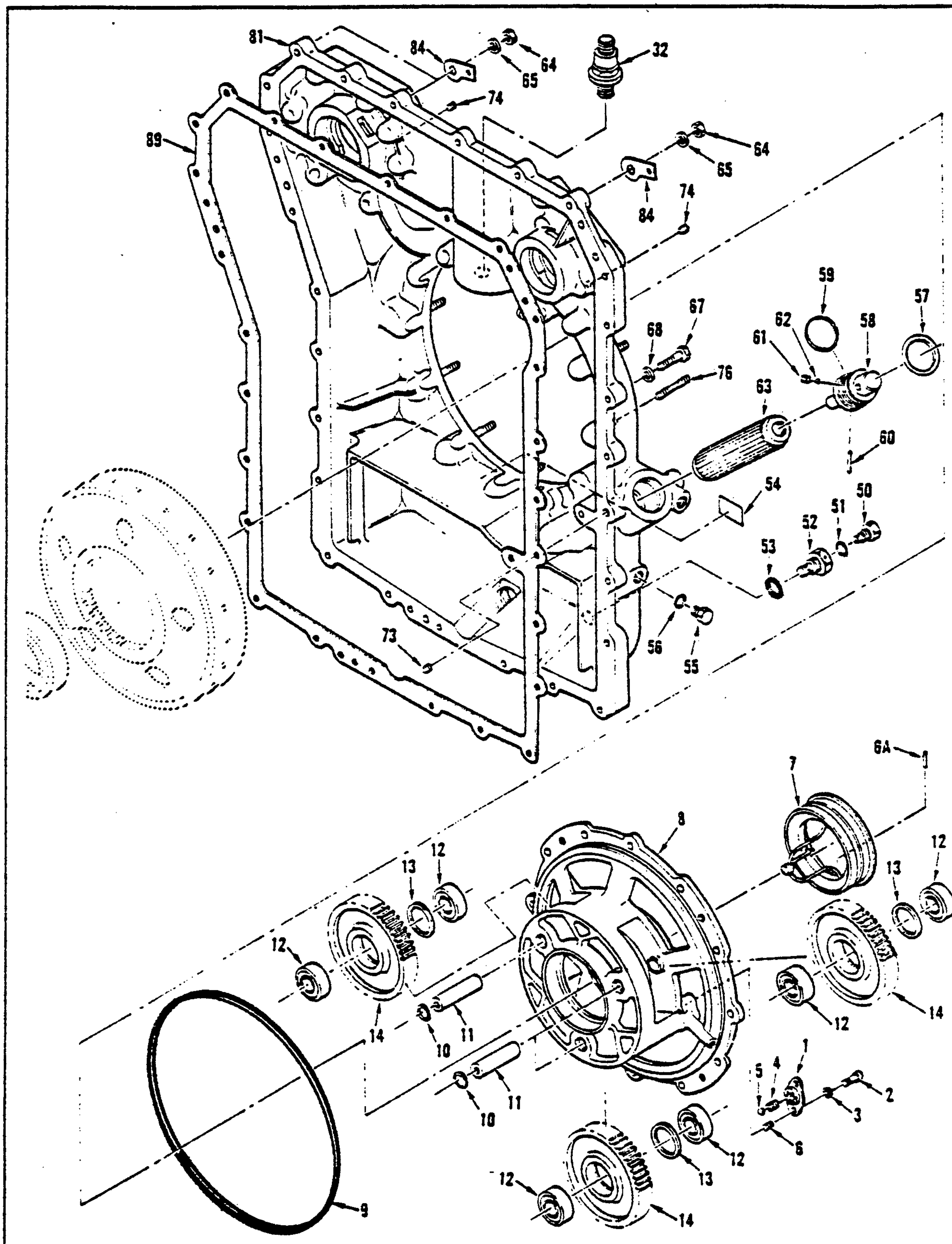


Figure 14. Gear Reduction and Accessory Drive Assembly (Sheet 2 of 2)

Variable Speed Alternators that can maintain the desirable constant output frequency while the speed of the alternator shaft can be variable in some limits aren't available on free market, at least, we couldn't find them.

All electrical motors could be used as alternators. Many types of motors are obsolete now. However, some of them, after some modifications, could be used as alternators. In this case, the experience in the development of those motors could be applied to the development of variable speed alternators. That can save the time and money not only during the research and development effort, but in the production and after sale service.

Some engineering improvements in the design of electrical machines for power generation applications have been developed by JSP Industries, Inc. and separately proposed.

Design of our brushless alternator was recently evaluated by National Institute of Standards and Technology (NIST). "We believe that the machine you proposed may find applications where small deviations from synchronous frequency are required" (quote from NIST evaluation report). This is exactly the application of this project.

Frequency Converters

Gen-sets with variable shaft speed diesel or gas turbine engines require some kind of AC-AC converters to transform variable frequency current to MIL-STD power with constant frequency (such as 60 Hz, 120 VAC).
This can be a two-step converter or a direct AC-AC converter.

The significant advantage of HFA-PFC Technology is capability to have both standard output military frequencies, 60 Hz and 400 Hz, from one gen-set. Both types of the frequency converters, AC-AC and AC-DC-AC converters, can have multi-frequency outputs.

Efficiency. The engine gen-sets could be used in two modes of operations:

1. 24-hour almost constant continuous load (radar stations, missile systems, etc.);

2. Mode that depends on the human activities when gen-sets are loaded about 75% of their rated load 14 hours during the daytime and about 25% during the nighttime.

We recommend using the AC-AC converters that could have an **efficiency up to 99%** for the first mode of operations, and AC-DC-AC converters in combination with the power storage devices for improved overall efficiency of the power system for the second mode of operations.

The AC-AC converters convert the high frequency input power from alternator directly to low frequency output power as shown on Figure 16, page 38. The simplified schematic diagram of the AC-AC converter ("Cycloconverter") is shown on Figure 17, page 38.

This type of AC-AC converter can provide an output waveform very close to sine, and have an **efficiency of about 94-96%.**

The losses in this type of converters are resistive on-state current losses in semiconductors (about 1%) plus switching losses. The switching losses during the switching cycle when the resistance of the semiconductor switches (Darlington transistors, IGBT transistors, SCRs, Triacs, etc.) changes from a very low state to a very high state and vice versa. The switching losses during one switching cycle can be computed using the next equation:

$$\Delta W = \int_{t_1}^{t_2} v(t) \cdot i(t) \cdot dt \qquad (1)$$

Where ΔW - switching losses;
$v(t)$ - voltage as function of time during one switching cycle;
$i(t)$ - current as function of time during one switching cycle;
t - time;
t_1 - beginning of switching cycle;
t_2 - finish of switching cycle;

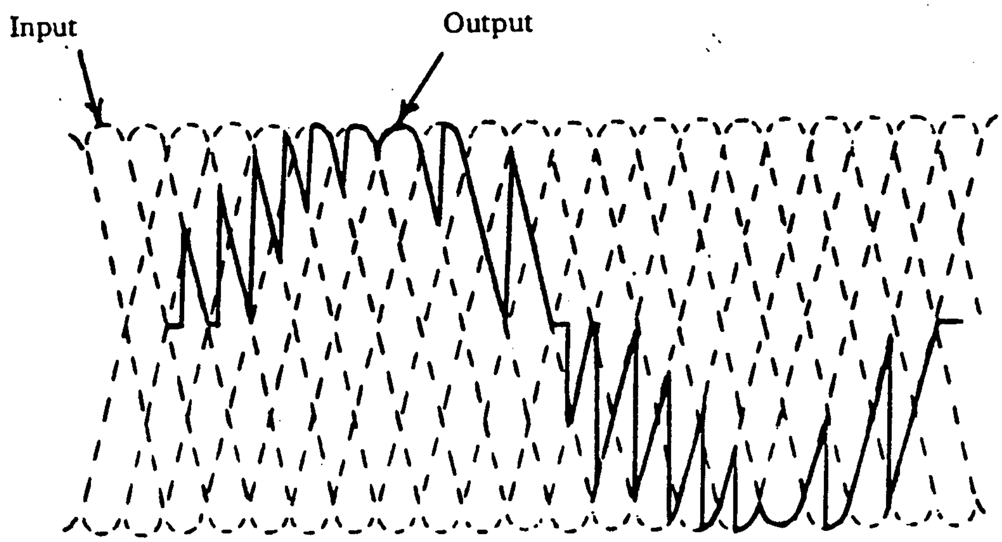
The switching losses are proportional to the switching frequency. For IGBTs, the switching losses are about 3-5% if the switching frequency is about 5-7 kHz. At higher switching frequencies the output waveform will improve, but the efficiency of the Cycloconverter will be lower.

Some engineering improvements in the design of the Cycloconverters for power generation applications have been developed by JSP Industries, Inc. and separately proposed.

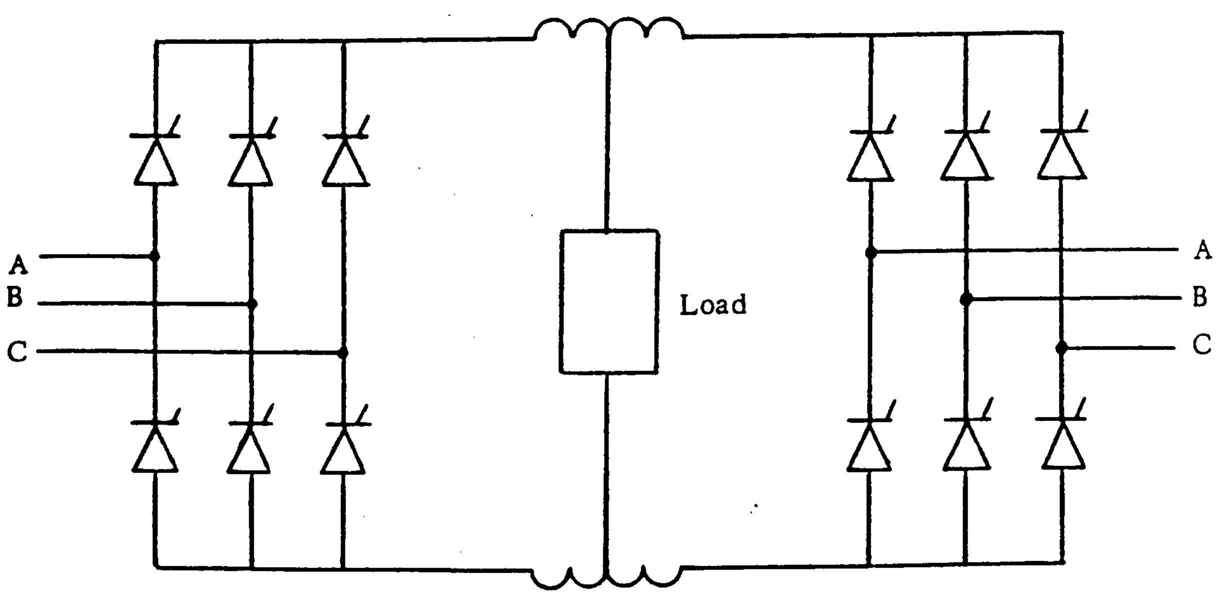
The efficiency of our converter could be close to 99% even at high switching frequencies up to 20 kHz.

We built two small prototypes of an AC-AC converter. The results of our tests have shown close relationship between the calculated losses and the actual losses of the real circuit. The deviation of voltage during our measurements didn't exceed +/- 2 V during the switching cycle at maximum switching frequencies of 20 kHz. This is good enough for a preliminary test. We plan more accurate tests for the first full scale prototype when we will use laminated bus bars.

The AC-DC-AC converters rectify the high frequency input power from the alternator to DC current, then the DC current is inverted to the AC current of the required frequency. The efficiency of this type of converter is about 94-96%.



Input – Output Characteristics (6 - Phase)
Figure 16.



Three Phase Full Wave Cycloconverter
Figure 17.

However, the advantage of this type of converter is presence of DC stage that could be connected to any type of energy storage devices (batteries, supercapacitors, flywheel storage devices, etc.). Because of this, the overall efficiency could be significantly increased.

For example, the daily load will be about 75% of the gen-set's rated load for 14 hours during the daytime and about 25% during the nighttime.

In this case the fuel consumption of the conventional 10 kW diesel gen-set will be:

0.405(lbs/HP·hr) x 7.5 HP x 14 hrs + .640(lbs/HP·hr) x 2.5 HP x 10 hrs = 58.5 lbs/day.

This computation is based on the data from Table 8, page 6, of our monthly report dated on 15 June 1995.

The fuel consumption of the diesel gen-set with a storage device will be:

.388 (lbs/HP·hr) x 10 HP x 12.5 hrs = 48.5 lbs/day, or about 10 lbs/day less compared to a conventional gen-set.

In this computation we didn't count losses in the energy storage device. We also assumed that the daily load will be about 75% of the gen-set's rated load for 14 hours during the daytime while. More than likely, during those 14 hours the load will drop below 75% many times. The actual savings in fuel consumption might be about 15-25%. That means that the transportation of the energy storage devices during military field operations is reasonable if the gen-sets will be used without movement for 2-3 weeks. In this case the weight of the saved fuel after 2-3 weeks will exceed the weight of the energy storage devices.

For more powerful diesel gen-sets, the usage of the energy storage devices could be even more efficient because their capacity increases faster than their weight, particularly for flywheel storage devices.

Output Waveform. The typical voltage waveform requirements for military gen-sets (60 kW alternator specification, US Air Force document No. 68A23340, page 10):

a. The 5-th harmonic shall not exceed 1.5% of the fundamental;
   the 7-th harmonic shall not exceed .75%;
   no other single harmonic shall exceed .5% of the fundamental.

b. The total harmonic content (square root of the sum of the squared values of all harmonics) shall not exceed 1.73%;

c. The crest factor shall be not more than 1.442 or less than 1.386.

All semiconductor frequency converters could be divided into two major groups:

1. Current source converters. This group of frequency converters designed to supply power to known constant load, usually equal to the rated power of the converter. In most cases it is an induction AC motor or transformer. The waveform of the output current in induction loads will be very close to sine, and any additional filtering of the output current isn't required.

2. Voltage source converters. This group of frequency converters designed to supply power to an unknown load, usually random combination of resistive, inductive, and capacitive loads from fraction to 125% of the rated power of the converter.

We believe that the general purpose military gen-sets based on HFA-PFC Technology should have the voltage source type of converters.

The output of all switching converters is some combination of voltage pulses.

For Pulse Width Modulated (PWM) type of converters with 5 pulses/half-cycle (600 Hz PWM control frequency) the output voltage and output current for inductive load (AC induction motor) are very close to sine, and only small ripples could be seen on the oscilloscope (3-phase, 10 HP converter with output frequency range from 3 to 90 Hz manufactured by Polyspede Electronics Corp.). The hardly visible high frequency ripples could be easily filtered, if required.

The increased rate of a PWM switching signal could improve the waveform further. We plan to increase the rate up to 40 pulse/half-cycle.

Another way to improve the output waveform is utilizing the microprocessor to generate the output waveform in *real-time* using feedback from the output voltage, current, power factor, etc. This system is used in C3+ Series of adjustable frequency converters manufactured by EMS, Fairfield, Ohio. We plan to use a similar technology in our voltage source type converters.

The voltage source type converters should have internal filters to provide the required waveform for any kind of load from unload condition to rated load.

The size of this 3-phase filter could be somewhat about the size of 1-2 kW, 3-phase, 60 Hz distribution transformer for 600 Hz inverter control PWM frequency.

At 6 kHz (50 pulses/half-cycle) inverter control PWM frequency for AC-DC-AC type of converter, the size of 3-phase filter will shrink even more.

At a 20 kHz inverter control PWM frequency for AC -AC type of converter the size of the filter will not be significant compared to other components.

Conclusion and Recomendations:

Results of the Phase I effort confirm feasibility of the HFA-PFC Technology. Existing alternator and power conversion technologies, including devices developed by JSP Industries, Inc., can be used for design of diesel and gas turbine gen-sets based on the HFA-PFC Technology.

We recommend to continue this project and build two full scale prototypes, 5 kW diesel gen-set and 60 kW gas turbine gen-set.

If we will have an opportunity to continue this project as the Phase II effort, we plan to get the next results:

1. We plan to have the final, ready for production prototype of the 5 kW diesel gen-set based on the HFA-PFC Technology at the and of the first year of the Phase II effort.

2. At the end of the Phase II effort we plan to have a detailed proposal of the product line based on HFA-PFC Technology diesel gen-sets in the range from 5 kW to 1,000 RPM for the Phase III effort.

3. At the end of the Phase II effort we plan to have the final, ready for production prototype of the 60 kW gas turbine gen-set based on HFA-PFC Technology.

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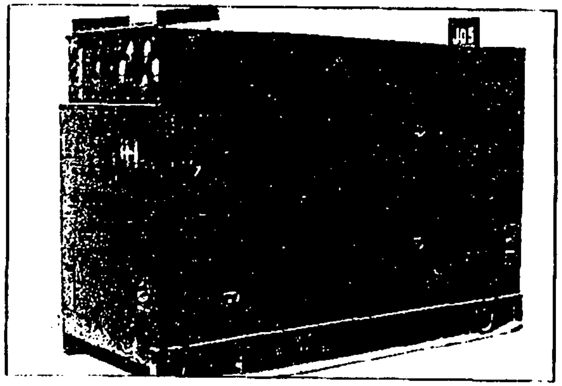
Appendixes

Appendix A

60kW PEP



GENERAL DESCRIPTION

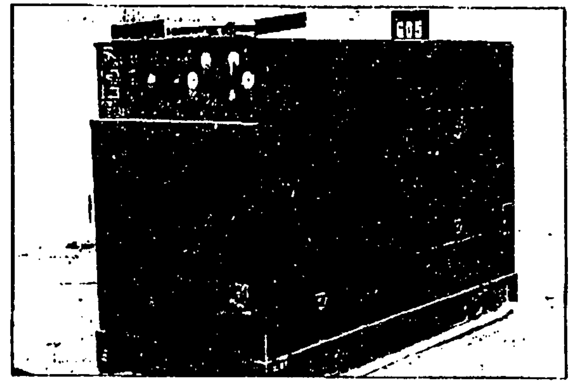
- Generator Set
- Diesel Engine Driven
- 60kW
- Tactical Quiet
- Noise Suppressed (70 dBA at 7 meters)
- HAEMP Protected

APPLICATIONS

- Weapon Systems
- Field Hospitals
- Water Purification Units
- Schools
- Topographic Support System
- Communications
- Aviation Ground Support
- Earth Satellite Terminals

	60Hz	400Hz
MEP No.	MEP-806A	MEP-816A
NSN	6115-01-274-7390	6115-01-274-7395
LIN	G12034	G18052
SSN	M534	M531

30kW PEP



GENERAL DESCRIPTION

- Generator Set
- Diesel Engine Driven
- 30kW
- Tactical Quiet
- Noise Suppressed (70 dBA at 7 meters)
- HAEMP Protected

APPLICATIONS

- Weapon Systems
- Missile Systems
- Water Purification
- Printing Plant
- Electronic and Communication Systems
- Bakery Plants
- ADP Systems
- Calibration Set
- Aviation Shop Sets

	60Hz	400Hz
MEP No.	MEP-805A	MEP-815A
NSN	6115-01-274-7389	6115-01-274-7394
LIN	G74575	G74643
SSN	M532	M501

60 kW

DIMENSIONS			
Length:	86.50 in.	Weight:	
Width:	35.25 in.	MEP-806A	4063 lbs.
Height:	58.00 in.	MEP-816A	4153 lbs.
Cube:	102.34 cu.ft.		

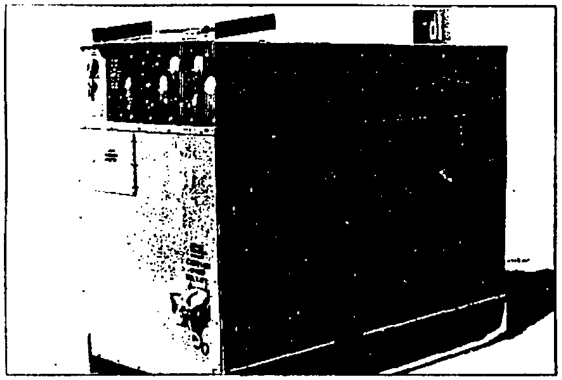
For More Information Contact:
United States Army
Belvoir Research Development
and Engineering Center
Fort Belvoir, VA 22060-5606

30 kW

DIMENSIONS			
Length:	79.25 in.	Weight:	
Width:	35.25 in.	MEP-805A	3006 lbs.
Height:	54.00 in.	MEP-815A	3015 lbs.
Cube:	87.30 cu.ft.		

For More Information Contact:
United States Army
Belvoir Research Development
and Engineering Center
Fort Belvoir, VA 22060-5606

15kW DED



GENERAL DESCRIPTION

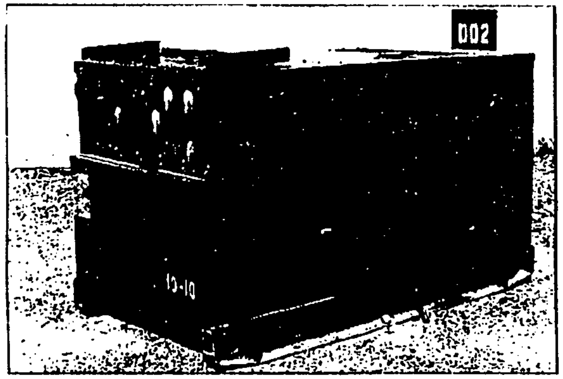
- Generator Set
- Diesel Engine Driven
- 15kW
- Tactical Quiet
- Noise Suppressed (70 dBA at 7 meters)
- HAEMP Protected

APPLICATIONS

- Weapon Systems
- Missile Systems
- Well Kit
- Printing Plant
- Topographic Support Systems
- Electronic Communications Systems
- Hospital Maintenance

	60Hz	400Hz
MEP No.	MEP-804A	MEP-814A
NSN	6115-01-274-7388	6115-01-274-7393
LIN	G12170	G12238
SSN	M549	M526

10kW DED



GENERAL DESCRIPTION

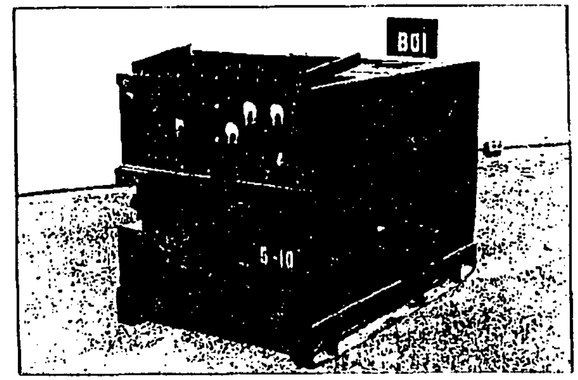
- Generator Set
- Diesel Engine Driven
- 10kW
- Tactical Quiet
- Noise Suppressed (70 dBA at 7 meters)
- HAEMP Protected

APPLICATIONS

- Weapon Systems
- Missile Systems
- Laundry Units
- Refrigeration
- Communication and Electronic Systems

	60Hz	400Hz
MEP No.	MEP-803A	MEP-813A
NSN	6115-01-275-5061	6115-01-274-7392
LIN	G74711	G74779
SSN	M529	M565

5kW DED



GENERAL DESCRIPTION

- Generator Set
- Diesel Engine Driven
- 5kW
- Tactical Quiet
- Noise Suppressed (70 dBA at 7 meters)
- HAEMP Protected

APPLICATIONS

- Weapon Systems
- Missile Systems
- Causeway Systems
- Communication and Electronic Systems

	60Hz	400Hz
MEP No.	MEP-802A	MEP-812A
NSN	6115-01-274-7387	6115-01-274-7391
LIN	G11966	G12102
SSN	M535	M518

15 kW

DIMENSIONS

Length:	69.25 in.	Weight:	
Width:	35.25 in.	MEP-804A	2124 lbs.
Height:	54.00 in.	MEP-814A	2238 lbs.
Cube:	76.28 cu.ft.		

For More Information Contact:
United States Army
Belvoir Research Development
and Engineering Center
■
Fort Belvoir, VA 22060-5606

10 kW

DIMENSIONS

Length:	61.75 in.	Weight:	
Width:	31.72 in.	MEP-803A	1182 lbs.
Height:	36.00 in.	MEP-813A	1220 lbs.
Cube:	40.81 cu.ft.		

For More Information Contact:
United States Army
Belvoir Research Development
and Engineering Center
■
Fort Belvoir, VA 22060-5606

5 kW

DIMENSIONS

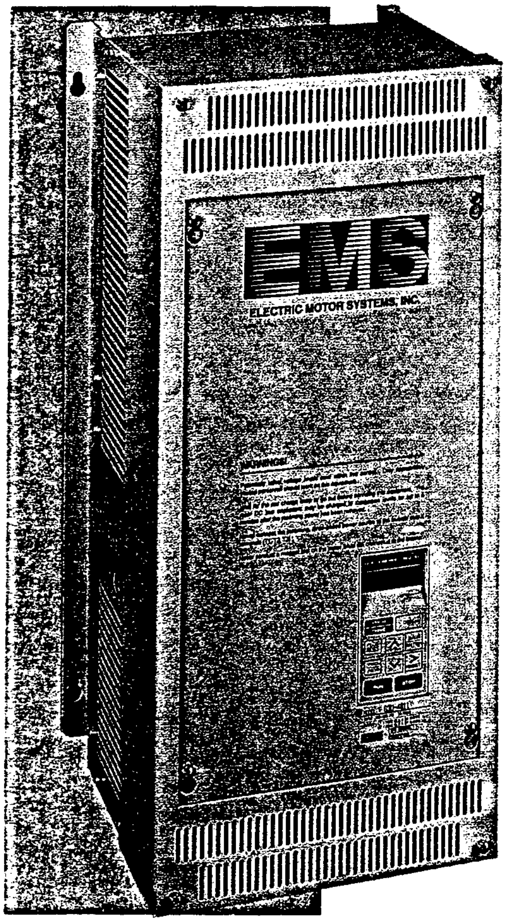
Length:	50.32 in.	Weight:	
Width:	31.72 in.	MEP-802A	888 lbs.
Height:	36.00 in.	MEP-812A	911 lbs.
Cube:	33.25 cu.ft.		

For More Information Contact:
United States Army
Belvoir Research Development
and Engineering Center
■
Fort Belvoir, VA 22060-5606

Appendix B

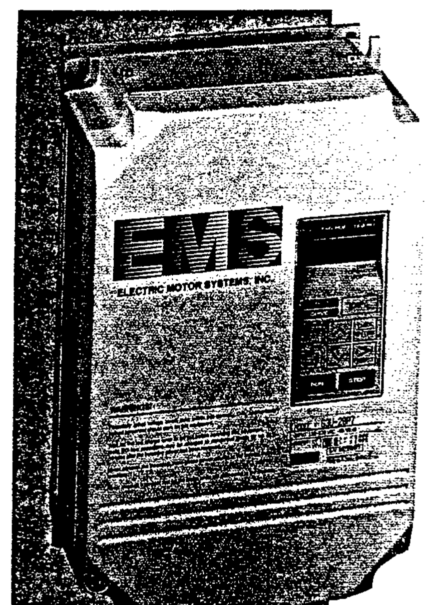
G3+ Series

Adjustable Frequency Drive



Constant Torque Ratings:
200 Volt Class: fractional to 100 Hp
400 Volt Class: fractional to 400 Hp

Variable Torque Ratings:
200 Volt Class: fractional to 125 Hp
400 Volt Class: fractional to 600 Hp



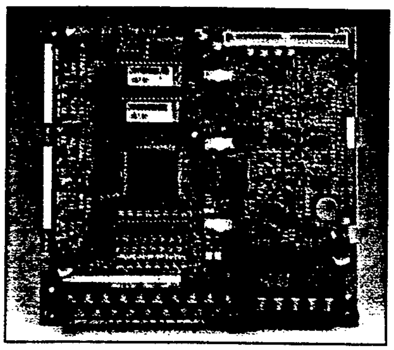
Celebrating over 50 years in the motor and control business !

The AC Motor Controller Which Has Defined the New World Standard for "General- purpose" Adjustable Frequency Drives !

G3+ epitomizes versatility with its vast software library of programmable I/O. These functions are field- configurable to meet the needs of a most applications.... with a single piece of hardware !

The **G3+** is our latest generation, microprocessor-based, adjustable frequency drive. It is an enhancement of our **G3** series unit, employing the latest micro-controller technology to remain on the leading edge of AC motor control. We are using a new, faster microprocessor operating with more, faster memory. This combination requires only 25% of the time to execute its program when compared to our **G3** unit, which was released with state-of-the-art technology only 2-1/2 years ago !

G3+ even supports a new, optional, keypad which was designed with the needs of the user in mind. It uses a 4-line, 14 character LCD display to provide detailed programming information for every parameter-giving the no., a brief description, the allowable range, the factory setting and the existing inverter data, in addition to the normal keypad functions.

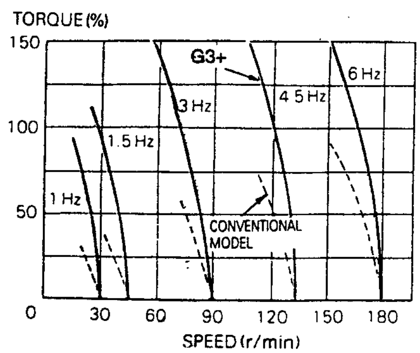


■ Designed With the Latest Technology- The **G3+** inverter employs the latest technology for superior reliability and ultra-compact design. The use of Surface Mount Technology (SMT) and customized Application Specific Integrated Circuits (ASICs) on the logic card are evidence of the manufacturing commitment to the future of our industry.

The SMT and ASICs allows for compact design, without compromising reliability... a perfect combination in today's competitive world in which plant floor space must be minimized, yet downtime cannot be tolerated.

■ High Torque at Low Speed- The **G3+** model inverter is capable of producing 100% motor rated torque down to 1.5 Hz! This is a *true*, 40:1 constant torque speed range. We can do this because of our unique, full-range, Automatic Torque Boost (ATB).

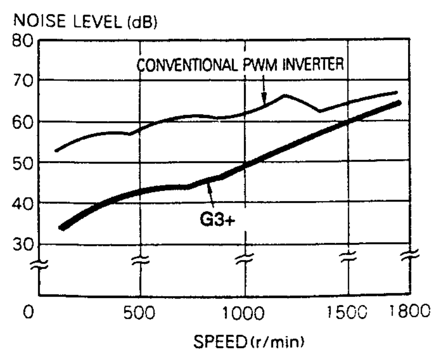
The **G3+** model uses a high speed microprocessor to generate the output waveform in *real-time*. This is more difficult to implement than the more conventional waveform generation methods, but it yields superior performance. We are, in effect, continuously "tuning" the output waveform in response to changing operating conditions.



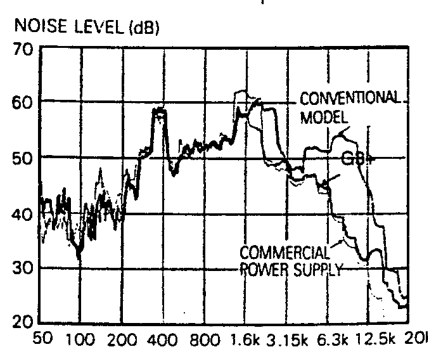
This sophisticated approach is required for ATB, which calculates any necessary voltage bias "on-the-fly". **ATB** is based upon *all* of the following variables: output voltage, current, frequency, power factor, motor iron and copper losses.

Just contrast this algorithm with the simple voltage boost method used by many competitors and you will see why our performance is second to none !

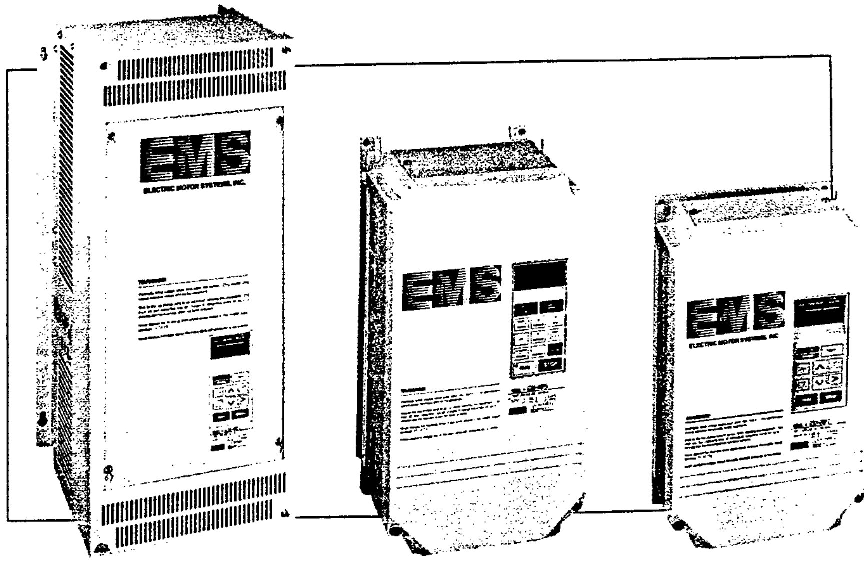
■ Low Audible Noise- Our original asynchronous, high carrier technique for generating the Pulse Width Modulated (PWM) output waveform has allowed us to eliminate the high-pitched "whine" of previous PWM units, without compromising low speed motor stability. Audible noise has been decreased by as much as 20 dB when compared to older designs.†



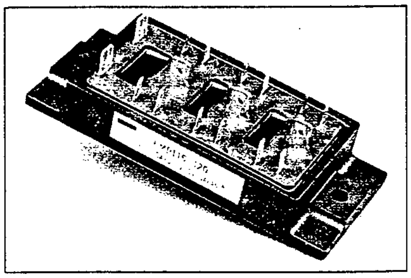
Compare a spectral analysis of the sound emitted by a **G3+** driven motor to that from operation across-the-line and you will see the noise added by the **G3+** is minimal (< 5 dB) across the entire audible spectrum.



† noise data applies only to units with carrier frequency set to 15 kHz

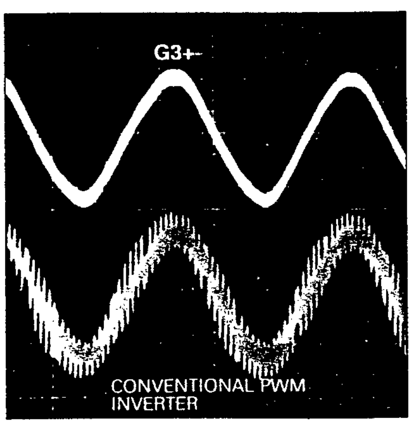


☐ **Using IGBTs**- All of the **G3+** models use the Insulated Gate Bipolar Transistor (IGBT) in their output section. This device has revolutionized the PWM inverter by facilitating higher switching frequencies. Further, it requires less componentry in its control circuitry.



This device has many advantages over its predecessor, the bipolar transistor. Some of these are:
* switching times equal to 10 % of the bipolar
* direct drive from the logic circuitry, eliminating the need for layer upon layer of base drive current amplification.
* a wider safe operating area for greater operating margin/ reliability.

The higher switching frequency of the IGBT also results in a smoother, more efficient motor current waveform.



☐ **Password Protected**- two separate levels of password protection can be used to protect programmed data from tampering.

☐ **Critical Frequency Rejection Points**- up to four independently programmable points can be assigned to protect the driven equipment from continuous operation at harmful resonance frequencies.

☐ **Electronic Motor Thermal Overload Protection**- allows you to program the motor's FLA and shape of the trip curve. A specific fault code is issued if this protective function is activated.

☐ **Fault History Function**- the 4 most recent fault codes are stored in the inverter's non-volatile memory- for review even after the input power is cycled off and on.

☐ **Overtorque Detection**- a programmable, "shear-pin" used to annunciate a condition in which the motor current has exceeded a programmed threshold for a time exceeding a programmed window. The **G3+** can provide a host of responses in reaction to an overtorque- ranging from annunciation only to a fault trip.

☐ **Running Current Limit**- if the output current exceeds a user-defined level, the output voltage and frequency will automatically decrease together, maintaining full motor torque, while preventing a nuisance fault trip.

☐ **Accel Current Limit**- used to prevent nuisance inverter trips due to rapid acceleration. The **G3+** will automatically extend the programmed accel ramp to limit the accel current.

☐ **2-wire or 3-wire Start/ Stop Control**

☐ **Preset Speeds**- up to 8 preset speeds can be selected (plus jog speed).

☐ **Preset V/F Patterns**- 15 factory preset patterns are available to choose from. In addition, it is possible to customize a pattern to match the needs of highly specialized motors or applications.

☐ **Accel/ Decel Ramps**- two sets are independently adjustable. Each is settable from 0.1 to 6000 secs.

☐ **S-curve**- you can select from any of three available times to smooth the accel/ decel of the driven machinery.

☐ **Analog Monitor**- a digitally scalable, multi-function output is available for master/ slave configurations, remote metering, etc. This output can be configured for frequency or load indication.

☐ **DC Injection Braking**

☐ **Automatic Fault Reset**- field programmable no. of "intelligent" automatic fault resets. They are intelligent because a component failure will prohibit any reset attempts, preventing the possibility of further damage.

☐ **Coast Stop or Ramp Stop**

☐ **Frequency Reference Loss Protection**- if the analog reference input signal decreases dramatically, the inverter can automatically default to 80% of the last valid frequency.

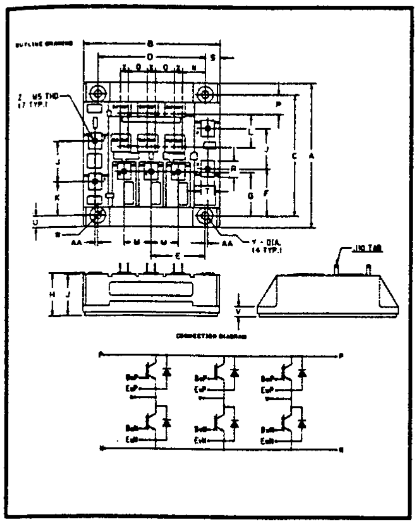
☐ **Speed Search**- an algorithm used to start into a spinning motor without a nuisance fault trip and without interrupting the motor's operation by first braking it to zero speed.

☐ **Inverted Master Frequency Reference**- the characteristic of output frequency vs. reference command can be inverted. This allows an increasing reference to result in a decreasing output frequency.

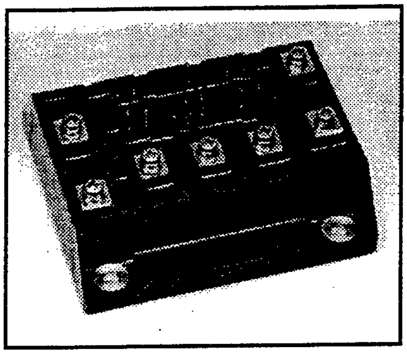
Appendix C

Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (412) 925-7272

Six-IGBT IGBTMOD™ H-Series Module
150 Amperes/600 Volts



CM150TF-12H
Outline Drawing



CM150TF-12H
Six-IGBT IGBTMOD™ H-Series Module
150 Amperes/600 Volts

Dimensions	Inches	Millimeters
A	4.21±0.02	107.0±0.5
B	4.02±0.02	102.0±0.5
C	3.543±0.01	90.0±0.25
D	3.15±0.01	80.0±0.25
E	2.01	51.0
F	1.38	35.0
G	1.28	32.5
H	1.26 Max.	32.0 Max
J	1.20	30.5
K	1.18	30.0
L	0.98	25.0
M	0.96	24.5
N	0.87	22.0
P	0.79	20.0
Q	0.67	17.0
R	0.55	14.0
S	0.47	12.0
T	0.43	11.0
U	0.39	10.0
V	0.33	8.5
W	0.31	8.0
X	0.24	6.0
Y	0.24 Rad.	Rad. 6.0
Z	0.216 Dia.	5.5 Dia.
AA	M5 Metric	M5
AB	0.08	2.0

Description:
Powerex IGBTMOD™ Modules are designed for use in switching applications. Each module consists of six IGBT Transistors in a three phase bridge configuration, with each transistor having a reverse-connected super-fast recovery free-wheel diode. All components and interconnects are isolated from the heat sinking baseplate, offering simplified system assembly and thermal management.

Features:
- ☐ Low Drive Power
- ☐ Low $V_{CE(sat)}$
- ☐ Discrete Super-Fast Recovery (70ns) Free-Wheel Diode
- ☐ High Frequency Operation (20-25kHz)
- ☐ Isolated Baseplate for Easy Heat Sinking

Applications:
- ☐ AC Motor Control
- ☐ Motion/Servo Control
- ☐ UPS
- ☐ Welding Power Supplies
- ☐ Laser Power Supplies

Ordering Information:
Example: Select the complete part module number you desire from the table below
-i.e. CM150TF-12H is a 600V (V_{CES}), 150 Ampere Six-IGBT IGBTMOD™ Power Module.

Type	Current Rating Amperes	V_{CES} Volts (x 50)
CM	150	12

POWEREX

Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (412) 925-7272

CM150TF-12H
Six-IGBT IGBTMOD™ H-Series Module
150 Amperes/600 Volts

Absolute Maximum Ratings, T_j = 25 °C unless otherwise specified

Ratings	Symbol	CM150TF-12H	Units
Junction Temperature	T_j	–40 to 150	°C
Storage Temperature	T_{stg}	–40 to 125	°C
Collector-Emitter Voltage (G-E SHORT)	V_{CES}	600	Volts
Gate-Emitter Voltage	V_{GES}	±20	Volts
Collector Current	I_C	150	Amperes
Peak Collector Current	I_{CM}	300*	Amperes
Diode Forward Current	I_{FM}	150	Amperes
Diode Forward Surge Current	I_{FM}	200*	Amperes
Power Dissipation	P_d	600	Watts
Max. Mounting Torque M5 Terminal Screws	–	20	kg-cm
Max. Mounting Torque M5 Mounting Screws	–	20	kg-cm
Module Weight (Typical)	–	830	Grams
V Isolation	V_{RMS}	2500	Volts

* Pulse width and repetition rate should be such that device junction temperature does not exceed the device rating.

Static Electrical Characteristics, T_j = 25 °C unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Collector-Cutoff Current	I_{CES}	$V_{CE} = V_{CES}$, $V_{GE} = 0V$	–	–	1.0	mA
Gate Leakage Current	I_{GES}	$V_{GE} = V_{GES}$, $V_{CE} = 0V$	–	–	0.5	µA
Gate-Emitter Threshold Voltage	$V_{GE(th)}$	I_C = 15mA, V_{CE} = 10V	4.5	6.0	7.5	Volts
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	I_C = 150A, V_{GE} = 15V	–	2.1	2.8**	Volts
		I_C = 150A, V_{GE} = 15V, T_j = 150°C	–	2.15	–	Volts
Total Gate Charge	Q_G	V_{CC} = 300V, I_C = 150A, V_{GS} = 15V	–	450	–	nC
Diode Forward Voltage	V_{FM}	I_E = 150A, V_{GE} = 0V	–	–	2.8	Volts

** Pulse width and repetition rate should be such that device junction temperature rise is negligible.

Dynamic Electrical Characteristics, T_j = 25 °C unless otherwise specified

Characteristics		Symbol	Test Conditions	Min.	Typ.	Max.	Units
Input Capacitance		C_{ies}	V_{GE} = 0V, V_{CE} = 10V, f = 1MHz	–	–	15	nF
Output Capacitance		C_{oes}		–	–	5.3	nF
Reverse Transfer Capacitance		C_{res}		–	–	3	nF
Resistive Load Switch Times	Turn-on Delay Time	$t_{d(on)}$	V_{CC} = 300V, I_C = 150A, $V_{GE1} = V_{GE2}$ = 15V, R_G = 4.2Ω	–	–	200	ns
	Rise Time	t_r		–	–	550	ns
	Turn-off Delay Time	$t_{d(off)}$		–	–	300	ns
	Fall Time	t_f		–	–	300	ns
Diode Reverse Recovery Time		t_{rr}	I_E = 150A, di_E/dt = –300A/µs	–	–	110	ns
Diode Reverse Recovery Charge		Q_{rr}	I_E = 150A, di_E/dt = –300A/µs	–	0.41	–	µC

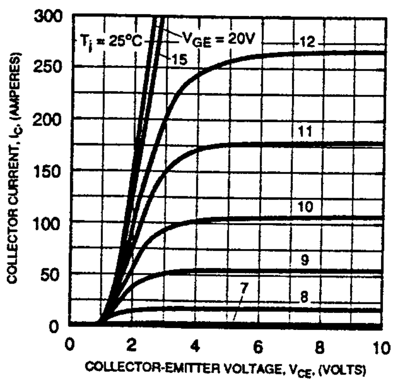
Thermal and Mechanical Characteristics, T_j = 25 °C unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Thermal Resistance, Junction to Case	$R_{th(j-c)}$	Per IGBT	–	–	0.21	°C/W
Thermal Resistance, Junction to Case	$R_{th(j-c)}$	Per Free Wheel Diode	–	–	0.47	°C/W
Contact Thermal Resistance	$R_{th(c-f)}$	Per 1/6 Module	–	–	0.13	°C/W

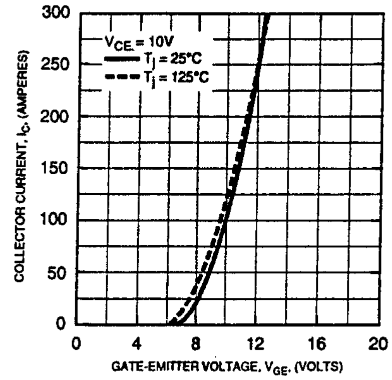
Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (412) 925-7272

CM150TF-12H
Six-IGBT IGBTMOD™ H-Series Module
150 Amperes/600 Volts

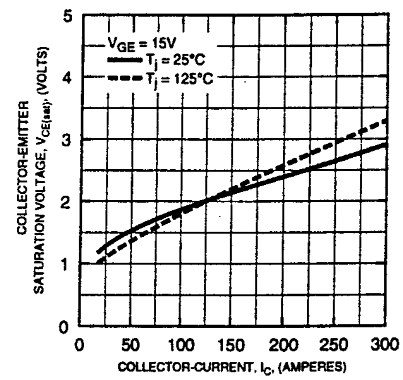
OUTPUT CHARACTERISTICS
(TYPICAL)



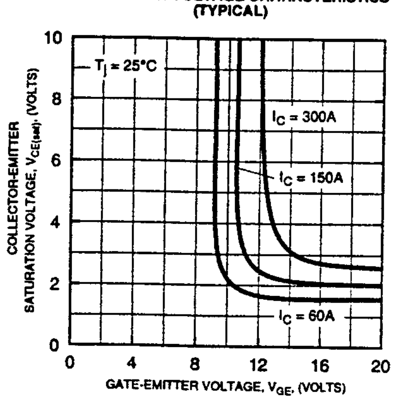
TRANSFER CHARACTERISTICS
(TYPICAL)



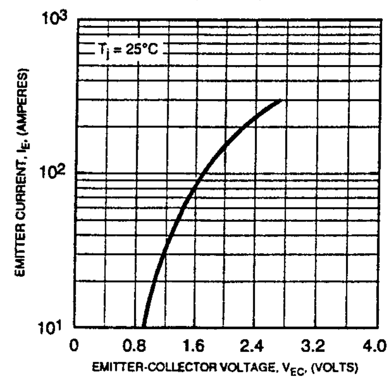
COLLECTOR-EMITTER
SATURATION VOLTAGE CHARACTERISTICS
(TYPICAL)



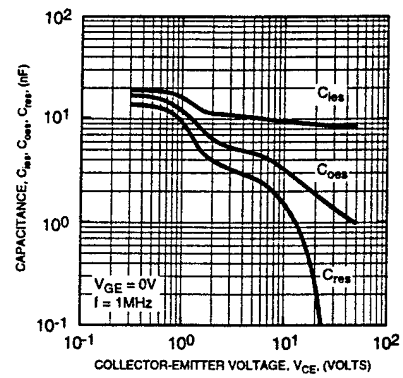
COLLECTOR-EMITTER
SATURATION VOLTAGE CHARACTERISTICS
(TYPICAL)



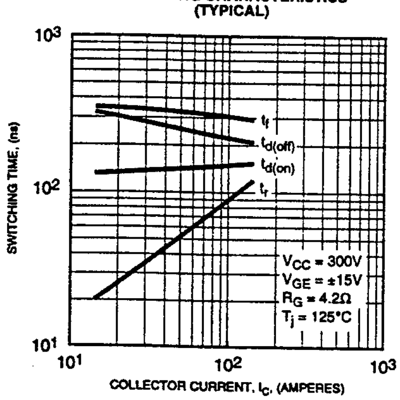
FREE-WHEEL DIODE
FORWARD CHARACTERISTICS
(TYPICAL)



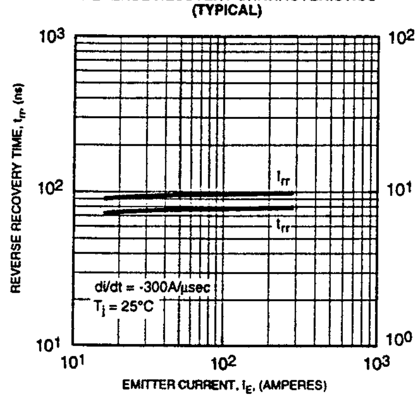
CAPACITANCE VS. V_{CE}
(TYPICAL)



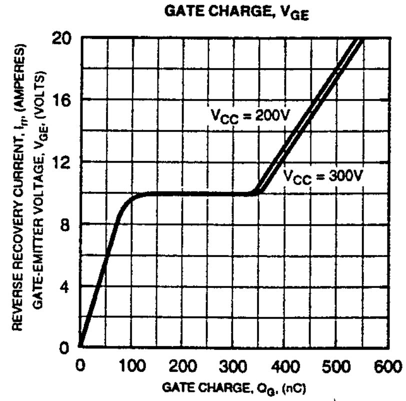
HALF-BRIDGE
SWITCHING CHARACTERISTICS
(TYPICAL)



REVERSE RECOVERY CHARACTERISTICS
(TYPICAL)



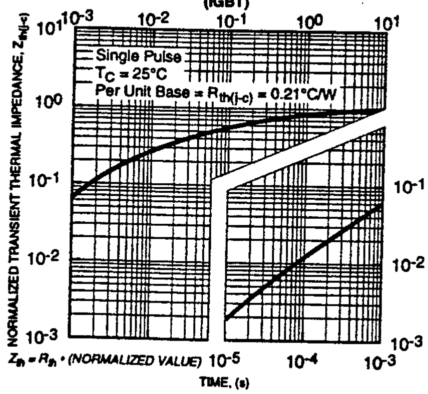
GATE CHARGE, V_{GE}



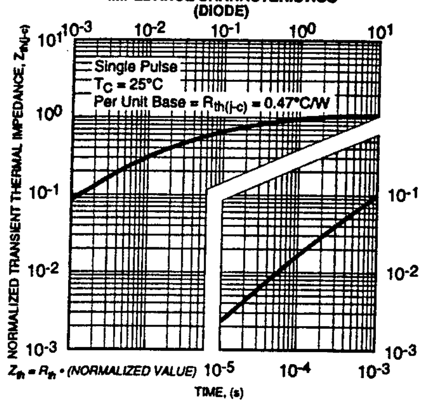
Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (412) 925-7272

CM150TF-12H
Six-IGBT IGBTMOD™ H-Series Module
150 Amperes/600 Volts

TRANSIENT THERMAL IMPEDANCE CHARACTERISTICS (IGBT)



TRANSIENT THERMAL IMPEDANCE CHARACTERISTICS (DIODE)

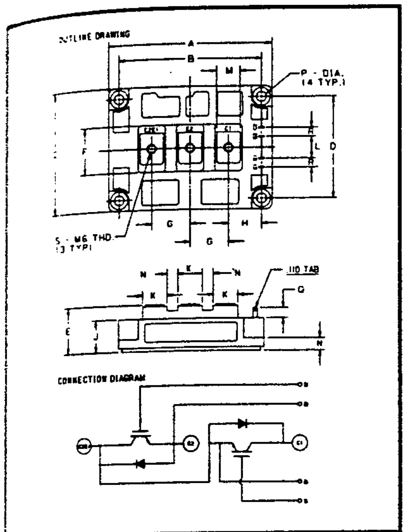


POWEREX

CM300DY-24H

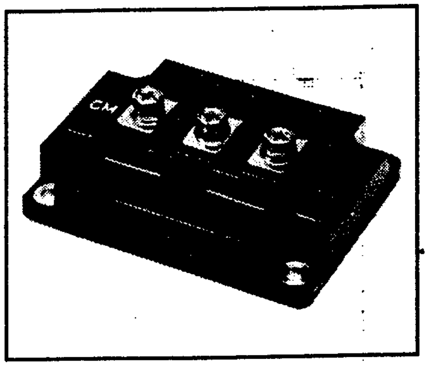
Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (412) 925-7272
Powerex, Europe, S.A. 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 41.14.14

Dual IGBTMOD™ H-Series Module
300 Amperes/1200 Volts



CM300DY-24H
Outline Drawing

Dimensions	Inches	Millimeters
A	4.33	110.0
B	3.661±0.01	93.0±0.25
C	3.15	80.0
D	2.441±0.01	62.0±0.25
E	1.18 Max.	30.0 Max.
F	1.18	30.0
G	0.98	25.0
H	0.85	21.5
J	0.83	21.2
K	0.71	18.0
L	0.59	15.0
M	0.55	14.0
N	0.28	7.0
P	0.26 Dia.	Dia. 6.5
Q	0.26	6.5
R	0.24	6.0
S	M6 Metric	M6



CM300DY-24H
Dual IGBTMOD™ H-Series Module
300 Amperes/1200 Volts

Description:
Powerex IGBTMOD™ Modules are designed for use in switching applications. Each module consists of two IGBT Transistors in a half-bridge configuration with each transistor having a reverse-connected super-fast recovery free-wheel diode. All components and interconnects are isolated from the heat sinking baseplate, offering simplified system assembly and thermal management.

Features:
- ☐ Low Drive Power
- ☐ Low $V_{CE(sat)}$
- ☐ Discrete Super-Fast Recovery (135ns) Free-Wheel Diode
- ☐ High Frequency Operation (20-25kHz)
- ☐ Isolated Baseplate for Easy Heat Sinking

Applications:
- ☐ AC Motor Control
- ☐ Motion/Servo Control
- ☐ UPS
- ☐ Welding Power Supplies
- ☐ Laser Power Supplies

Ordering Information:
Example: Select the complete part module number you desire from the table below
-i.e. CM300DY-24H is a 1200V (V_{CES}), 300 Ampere Dual IGBTMOD™ Power Module.

Type	Current Rating Amperes	V_{CES} Volts (x 50)
CM	300	24

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POWEREX

Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (412) 925-7272
Powerex, Europe, S.A. 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 41.14.14

CM300DY-24H
Dual IGBTMOD™ H-Series Module
300 Amperes/1200 Volts

Absolute Maximum Ratings, T_j = 25 °C unless otherwise specified

Ratings	Symbol	CM300DY-24H	Units
Junction Temperature	T_j	–40 to 150	°C
Storage Temperature	T_{stg}	–40 to 125	°C
Collector-Emitter Voltage (G-E SHORT)	V_{CES}	1200	Volts
Gate-Emitter Voltage	V_{GES}	±20	Volts
Collector Current	I_C	300	Amperes
Peak Collector Current	I_{CM}	600*	Amperes
Diode Forward Current	I_{FM}	300	Amperes
Diode Forward Surge Current	I_{FM}	600*	Amperes
Power Dissipation	P_d	2100	Watts
Max. Mounting Torque M6 Terminal Screws	–	26	in-lb
Max. Mounting Torque M6 Mounting Screws	–	26	in-lb
Module Weight (Typical)	–	500	Grams
V Isolation	V_{RMS}	2500	Volts

* Pulse width and repetition rate should be such that device junction temperature does not exceed the device rating.

Static Electrical Characteristics, T_j = 25 °C unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Collector-Cutoff Current	I_{CES}	$V_{CE} = V_{CES}$, $V_{GE} = 0V$	–	–	1.0	mA
Gate Leakage Current	I_{GES}	$V_{GE} = V_{GES}$, $V_{CE} = 0V$	–	–	0.5	μA
Gate-Emitter Threshold Voltage	$V_{GE(th)}$	I_C = 30mA, V_{CE} = 10V	4.5	6.0	7.5	Volts
Collector-Emitter Saturation Voltage	$V_{CE(sat)}$	I_C = 300A, V_{GE} = 15V	–	2.5	3.2**	Volts
		I_C = 300A, V_{GE} = 15V, T_j = 150°C	–	2.25	–	Volts
Total Gate Charge	Q_G	V_{CC} = 600V, I_C = 300A, V_{GS} = 15V	–	1500	–	nC
Diode Forward Voltage	V_{FM}	I_E = 300A, V_{GS} = 0V	–	–	3.4	Volts

** Pulse width and repetition rate should be such that device junction temperature rise is negligible.

Dynamic Electrical Characteristics, T_j = 25 °C unless otherwise specified

Characteristics		Symbol	Test Conditions	Min.	Typ.	Max.	Units
Input Capacitance		C_{ies}	V_{GE} = 0V, V_{CE} = 10V, f = 1MHz	–	–	60	nF
Output Capacitance		C_{oes}		–	–	21	nF
Reverse Transfer Capacitance		C_{res}		–	–	12	nF
Resistive Load Switch Times	Turn-on Delay Time	$t_{d(on)}$	V_{CC} = 600V, I_C = 300A, $V_{GE1} = V_{GE2}$ = 15V, R_G = 1.0Ω	–	–	250	ns
	Rise Time	t_r		–	–	500	ns
	Turn-off Delay Time	$t_{d(off)}$		–	–	350	ns
	Fall Time	t_f		–	–	350	ns
Diode Reverse Recovery Time		t_{rr}	I_E = 300A, di_E/dt = –600A/μs	–	–	250	ns
Diode Reverse Recovery Charge		Q_{rr}	I_E = 300A, di_E/dt = –600A/μs	–	2.23	–	μC

Thermal and Mechanical Characteristics, T_j = 25 °C unless otherwise specified

Characteristics	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Thermal Resistance, Junction to Case	$R_{th(j-c)}$	Per IGBT	–	–	0.06	°C/W
Thermal Resistance, Junction to Case	$R_{th(j-c)}$	Per Free Wheel Diode	–	–	0.12	°C/W
Contact Thermal Resistance	$R_{th(c-f)}$	Per Half Module	–	–	0.07	°C/W

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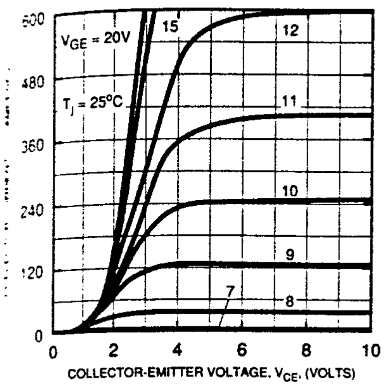
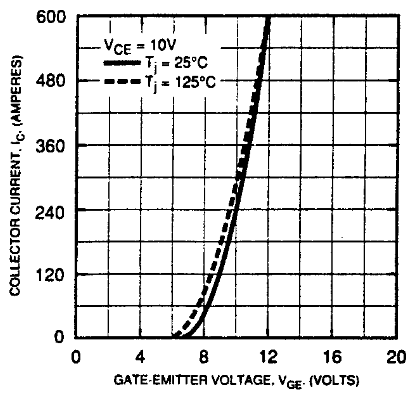
Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (412) 925-7272
Powerex, Europe, S.A. 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 41.14.14

CM300DY-24H
Dual IGBTMOD™ H-Series Module
300 Amperes/1200 Volts

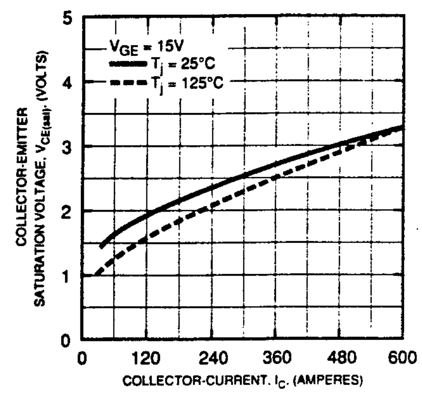
OUTPUT CHARACTERISTICS
(TYPICAL)



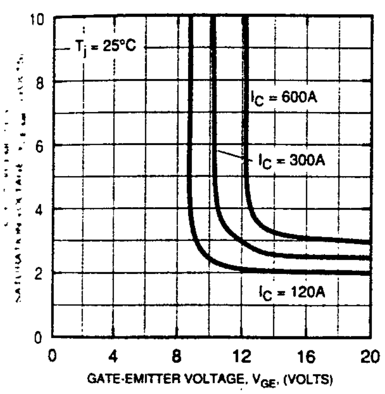
TRANSFER CHARACTERISTICS
(TYPICAL)



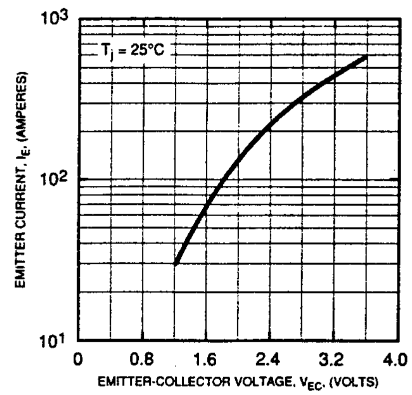
COLLECTOR-EMITTER
SATURATION VOLTAGE CHARACTERISTICS
(TYPICAL)



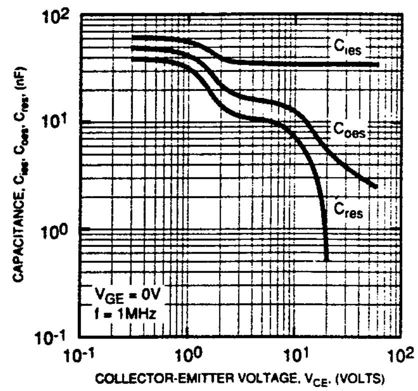
COLLECTOR-EMITTER
SATURATION VOLTAGE CHARACTERISTICS
(TYPICAL)



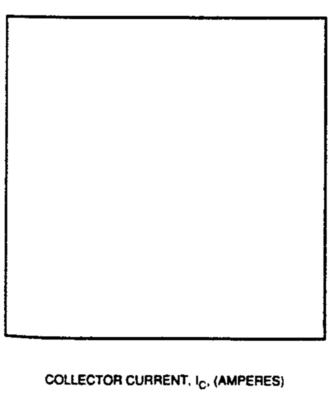
FREE-WHEEL DIODE
FORWARD CHARACTERISTICS
(TYPICAL)



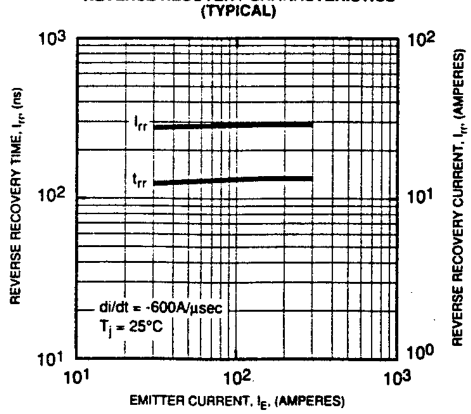
CAPACITANCE VS. V_{CE}
(TYPICAL)



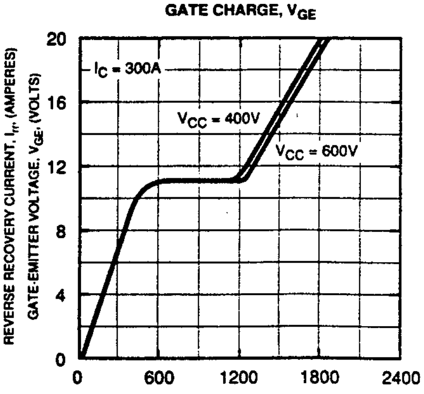
HALF-BRIDGE
SWITCHING CHARACTERISTICS
(TYPICAL)



REVERSE RECOVERY CHARACTERISTICS
(TYPICAL)



GATE CHARGE, V_{GE}



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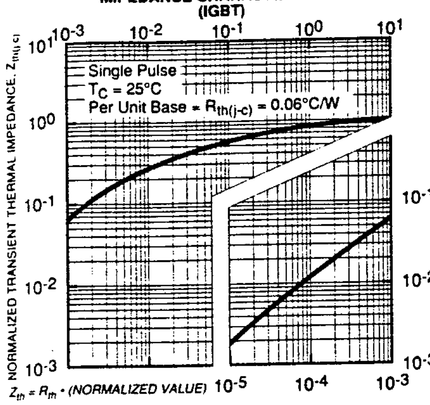
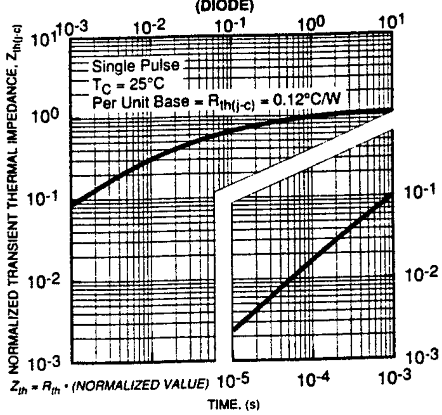
Powerex, Europe, S.A. 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 41.14.14

CM300DY-24H
Dual IGBTMOD™ H-Series Module
300 Amperes/1200 Volts

TRANSIENT THERMAL IMPEDANCE CHARACTERISTICS (IGBT)



TRANSIENT THERMAL IMPEDANCE CHARACTERISTICS (DIODE)



Appendix D

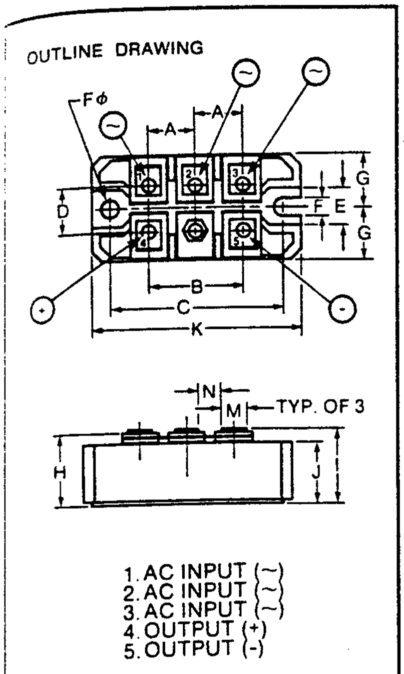
POWEREX

ME30 __ __ A7

Powerex, Inc., Hillis Street, Youngwood, Pennsylvania 15697 (412) 925-7272
Powerex Europe, S.A., 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 72.75.15

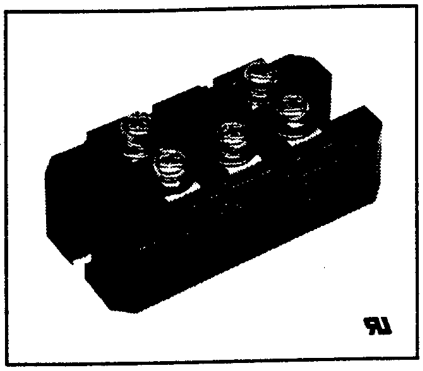
Three-Phase Diode Bridge Module

75 Amperes/600-1600 Volts



600-1600 Volts ME30 __ __ A7 Outline Drawing

Dimension	Inches	Millimeters
A	0.709 ± .012	18.0 ± 0.3
B	1.417 ± .020	36.0 ± 0.5
C	2.60 ± .008	66.0 ± 0.2
D	.670	16.0
E	.551	14.0
F	.256	6.5
G	.787	20.0
H	1.063	27.0 Max.
I	1.102	28.0 Max.
J	.906	23.0 Max.
K	3.15	80.0 Max.
M	.374	9.5
N	.315	8.0 Min.



ME30 __ __ A7
Three-Phase Diode Bridge Module
75 Amperes/600-1600 Volts

Description

Powerex Three-Phase Diode Bridge Modules are designed for use in three phase bridge applications. The modules are isolated consisting of six rectifier diodes. These ME30 Modules have been tested and recognized by Underwriters Laboratories (QQQX2 Power Switching Semiconductors).

Features:

- ☐ Multiple Chip in Electrically Isolated Package
- ☐ Glass Passivated Chips
- ☐ High Surge Current
- ☐ Compact Package
- ☐ UL Recognized

Benefits:

- ☐ Reduced Component Count and Assembly Time
- ☐ Long-Term Voltage Stability
- ☐ Improved Tolerance to Overcurrent
- ☐ Minimize System Size

Applications:

- ☐ A.C. Motor Control
- ☐ D.C. Motor Control
- ☐ Battery Charger
- ☐ D.C. Power Supplies

Ordering Information

Example: Select the complete eight digit module part number you desire from the table — i.e. ME3012A7 is a 1200 Volt, 75 Ampere Three-Phase Diode Bridge Module.

Type	V_{RRM} Volts (x100)	Current Rating Amperes (75)
ME30	06	A7
	12	
	16	

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POWEREX

Powerex, Inc., Hillis Street, Youngwood, Pennsylvania 15697 (412) 925-7272
Powerex Europe, S.A., 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 72.75.15

ME30 _ _ A7
Three-Phase Diode Bridge Module
75 Amperes/600-1600 Volts

Absolute Maximum Ratings

Characteristics	Symbol	ME3006A7	ME3012A7	ME3016A7	Units
Peak Reverse Blocking Voltage	V_{RRM}	600	1200	1600	Volts
Transient Peak Reverse Blocking Voltage (Non-Repetitive) t<5ms	V_{RSM}	720	1350	1700	Volts
Reverse Blocking Voltage	$V_{R(DC)}$	480	960	1280	Volts
Output Current, $T_C = 100°C$	I_O	75	75	75	Amperes
Peak One-Cycle Surge (Non-Repetitive) On-State Current (60 Hz)	I_{FSM}	820	820	820	Amperes
Peak One-Cycle Surge (Non-Repetitive) On-State Current (50 Hz)	I_{FSM}	750	750	750	Amperes
I^2t (for Fusing), 8.3 milliseconds	I^2t	2800	2800	2800	A^2sec
Storage Temperature	T_{STG}	-40 to 125	-40 to 125	-40 to 125	°C
Operating Temperature	T_J	-40 to 150	-40 to 150	-40 to 150	°C
Maximum Mounting Torque M6 Mounting Screw	—	26	26	26	in.-lb.
Maximum Terminal Torque M5 Terminal Screw	—	17	17	17	in.-lb.
Module Weight (Typical)	—	230	230	230	Grams
V Isolation	V_{RMS}	2000	2000	2000	Volts

Powerex, Inc., Hillis Street, Youngwood, Pennsylvania 15697 (412) 925-7272
Powerex Europe, S.A., 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 72.75.15

ME30 __ __ A7
Three-Phase Diode Bridge Module
Amperes/600-1600 Volts

Electrical and Thermal Characteristics, $T_J = 25°C$ unless otherwise specified

Characteristic	Symbol	Test Conditions	ME30 __ __ A7	Units
Blocking State Maximums				
Reverse Leakage Current, Peak	I_{RRM}	$T_J = 150°C$, V_{RRM} = rated	5	mA
Conducting State Maximums				
Peak On-State Voltage	V_{FM}	$I_{FM} = 100A$	1.3	Volts
Thermal Maximums				
Thermal Resistance, Junction to Case	$R_{\theta JC}$	Per Module	0.27	°C/Watt
Thermal Resistance, Case to Sink Lubricated	$R_{\theta CS}$	Per Module	—	°C/Watt

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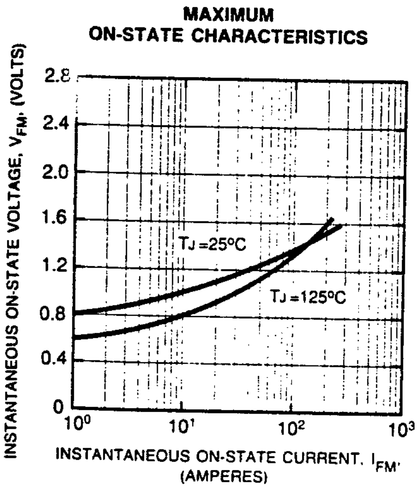
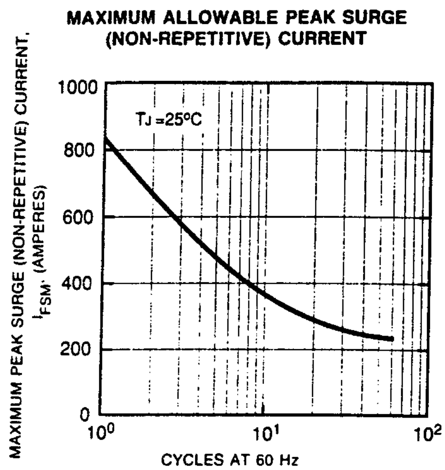
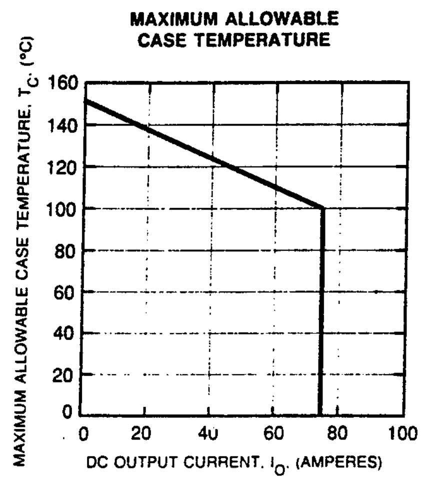
POWEREX

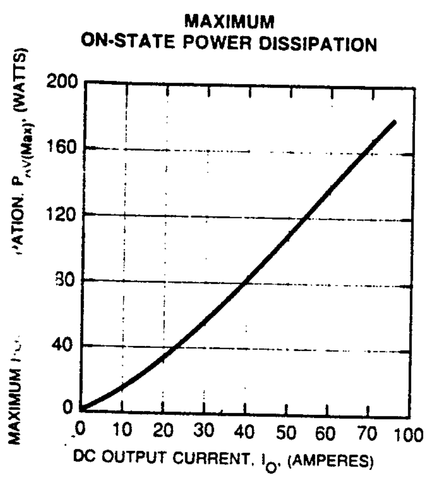
Powerex, Inc., Hillis Street, Youngwood, Pennsylvania 15697 (412) 925-7272
Powerex Europe, S.A., 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 72.75.15

ME30 _ _ A7
Three-Phase Diode Bridge Module
75 Amperes/600-1600 Volts







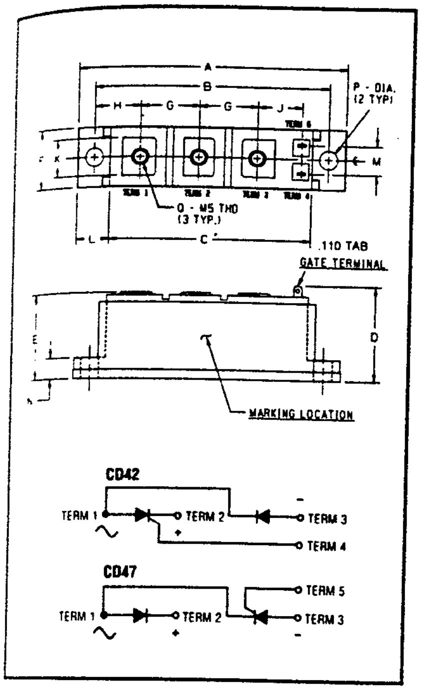


POWEREX

CD42 _ _ 90
CD47 _ _ 90

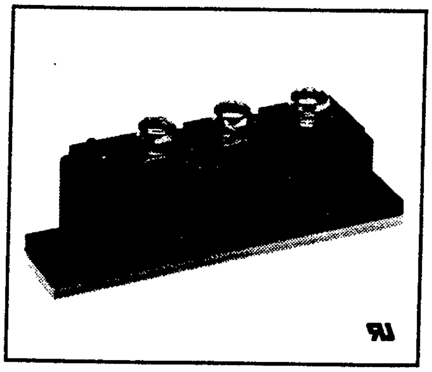
Powerex, Inc., Hillis Street, Youngwood, Pennsylvania 15697 (412) 925-7272
Powerex Europe, S.A., 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 72.75.15

SCR/Diode POW-R-BLOK™ Modules
90 Amperes/100-1400 Volts



100-1400 Volts
CD42 _ _ 90, CD47 _ _ 90
Outline Drawing

Dimension	Inches Min.	Inches Max.	Millimeters Min.	Millimeters Max.
A	3.602	3.640	91.49	92.45
B	3.146	3.154	79.91	80.11
C	2.705	2.735	68.71	69.47
D	1.24	1.28	31.50	32.51
E	1.125	1.165	28.58	29.59
F	.795	.805	20.19	20.45
G	.788	.798	19.76	20.27
H	.608	.628	15.44	15.95
J	.585	.605	14.86	15.36
K	.480	.520	12.19	13.21
L	.43	.47	10.92	11.94
M	.36	.40	9.14	10.16
N	.265	.285	6.73	7.24
P	.245	.255	6.22	6.48
Q	—	—	M5 x 0.8	



CD42 _ _ 90, CD47 _ _ 90
SCR/Diode POW-R-BLOK™ Modules
90 Amperes/100-1400 Volts

Ordering Information
Example: Select the complete eight digit rating module part number you desire from the table — i.e. CD420890 is an 800 Volt, 90 Ampere SCR/Diode POW-R-BLOK™ Module.

Type	V_{RRM} Volts (x100)	Current Rating Amperes (90)
CD42	01	90
CD47	02	
	04	
	06	
	08	
	10	
	12	
	14	

Description
Powerex SCR/Diode POW-R-BLOK™ Modules combine multiple power semiconductor devices in a single, electrically isolated module. This dense, cost-effective packaging is made possible by Powerex's proprietary *glass passivation* process, in which each semiconductor junction is sealed with a protective layer of glass. Exhaustive testing at high voltages and high temperatures has demonstrated the excellent parameter stability of these glass-protected products.

The POW-R-BLOK™ features a self-contained electrical isolation system. The use of BeO ceramic isolators with high thermal conductivity has achieved excellent circuit-to-baseplate isolation (≥2500 volts RMS), while maintaining efficient cooling of the semiconductors. POW-R-BLOK™ has been tested and recognized by Underwriters Laboratories (QQQX2 Power Switching Semiconductors).

Features:
- ☐ Glass Passivated Chips
- ☐ Hybrid Construction
- ☐ Isolated Base Plate
- ☐ Low Thermal Impedance
- ☐ Metal Base Plate
- ☐ UL Recognized
- ☐ Quick Connect Gate Terminals

Applications:
- ☐ Motor Speed Control
- ☐ Battery Chargers
- ☐ Tap Changers
- ☐ Transfer Switches
- ☐ Lighting Controls
- ☐ Power Line Applications of 120, 240 or 480 Volts

Benefits:
- ☐ No Additional Insulating Components Required
- ☐ Easy Installation
- ☐ Reduced Engineering Time
- ☐ Improved Heat Transfer
- ☐ Voltage Stability

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CD42 _ _ 90, CD47 _ _ 90
SCR/Diode POW-R-BLOK™ Modules
90 Amperes/100-1400 Volts

Absolute Maximum Ratings

Characteristics	Symbol	CD420190 CD470190	CD420290 CD470290	CD420490 CD470490	CD420690 CD470690	Units
Peak Forward Blocking Voltage	V_{DRM}	100	200	400	600	Volts
Peak Reverse Blocking Voltage	V_{RRM}	100	200	400	600	Volts
Transient Peak Reverse Blocking Voltage (Non-Repetitive) t<5 ms	V_{RSM}	200	300	500	700	Volts

Characteristics	Symbol	CD420890 CD470890	CD421090 CD471090	CD421290 CD471290	CD421490 CD471490	Units
Peak Forward Blocking Voltage	V_{DRM}	800	1000	1200	1400	Volts
Peak Reverse Blocking Voltage	V_{RRM}	800	1000	1200	1400	Volts
Transient Peak Reverse Blocking Voltage (Non-Repetitive) t<5 ms	V_{RSM}	950	1200	1450	1700	Volts

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CD42 __ __ 90, CD47 __ __ 90
SCR/Diode POW-R-BLOK™ Modules
90 Amperes/100-1400 Volts

Absolute Maximum Ratings

Characteristics	Symbol	CD42 __ __ 90 CD47 __ __ 90	Units
RMS On-State Current	$I_{T(RMS)}$, $I_{F(RMS)}$	145	Amperes
Average On-State Current	$I_{T(AV)}$, $I_{F(AV)}$	90	Amperes
Peak One-Cycle Surge (Non-Repetitive) On-State Current (60Hz)	I_{TSM}, I_{FSM}	1925	Amperes
Peak Three-Cycle Surge (Non-Repetitive) On-State Current (60Hz)	I_{TSM}, I_{FSM}	1390	Amperes
Peak Ten-Cycle Surge (Non-Repetitive) On-State Current (60Hz)	I_{TSM}, I_{FSM}	1250	Amperes
Peak One-Cycle Surge (Non-Repetitive) On-State Current (50Hz)	I_{TSM}, I_{FSM}	1755	Amperes
I^2t (for Fusing), 8.3 milliseconds	I^2t	15375	A^2sec
Critical Rate-of-Rise of On-State Current ① (Non-Repetitive)	di/dt	800	Amperes/μs
Peak Gate Power Dissipation	P_{GM}	16	Watts
Average Gate Power Dissipation	$P_{G(AV)}$	3.0	Watts
Peak Forward Gate Voltage	V_{GFM}	10	Volts
Peak Reverse Gate Voltage	V_{GRM}	5.0	Volts
Peak Forward Gate Current	I_{GFM}	4.0	Amperes
Storage Temperature	T_{STG}	−40 to 150	°C
Operating Temperature	T_J	−40 to 125	°C
Maximum Mounting Torque M6 Mounting Screw	—	50	in.-lb.
Maximum Terminal Torque M5 Terminal Screw	—	35	in.-lb.
Module Weight (Typical)	—	142	Grams
Isolation	V_{RMS}	2500	Volts

① Per JEDEC STD RS-397, 5.2.2.6.

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CD42 __ __ 90, CD47 __ __ 90
SCR/Diode POW-R-BLOK™ Modules
90 Amperes/100-1400 Volts

Electrical and Thermal Characteristics, $T_J = 25°C$ unless otherwise specified

Characteristic	Symbol	Test Conditions	CD42 __ __ 90 CD47 __ __ 90	Units
Blocking State Maximums				
Forward Leakage Current, Peak	I_{DRM}	$T_J = 125°C$, V_{DRM} = rated	15	mA
Reverse Leakage Current, Peak	I_{RRM}	$T_J = 125°C$, V_{RRM} = rated	15	mA
Conducting State Maximums				
Peak On-State Voltage	V_{TM}	$I_{TM} = 250A$	1.55	Volts
Peak On-State Voltage	V_{FM}	$I_{FM} = 250A$	1.3	Volts
Switching Minimums				
Critical Rate of Rise of Off-State Voltage	dv/dt	$T_J = 125°C$, Exponential to V_{DRM}	300	Volts/μsec
Typical Turn-Off Time	t_q	$I_{TM} = 50A$, $T_J = 125°C$, $di_R/dt = 5A/\mu s$ reapplied $dv/dt = 20V/\mu s$ linear to 0.8 V_{DRM}	100	μsec
Typical Turn-On Time	t_{on}	$I_{TM} = 100A$, $V_D = 100V$	4	μsec
Thermal Maximums				
Thermal Resistance, Junction to Case	$R_{\theta JC}$	Per Device	0.28	°C/Watt
Thermal Resistance, Case to Sink Lubricated	$R_{\theta CS}$	Per Device	0.2	°C/Watt
Gate Parameters Maximums				
Gate Current to Trigger	I_{GT}	$V_D = 12V$	100	mA
Gate Voltage to Trigger	V_{GT}	$V_D = 12V$	3.0	Volts
Non-Triggering Gate Voltage	V_{GDM}	$T_J = 125°C$, $V_D = V_{DRM}$	0.15	Volts

WARNING:
Internal insulation used is Beryllium Oxide. User should avoid grinding, crushing or abrading these portions. Care must be exercised in properly disposing of unwanted modules.

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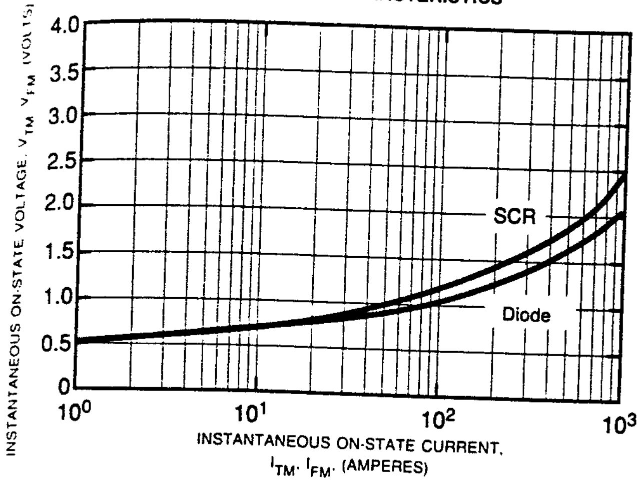
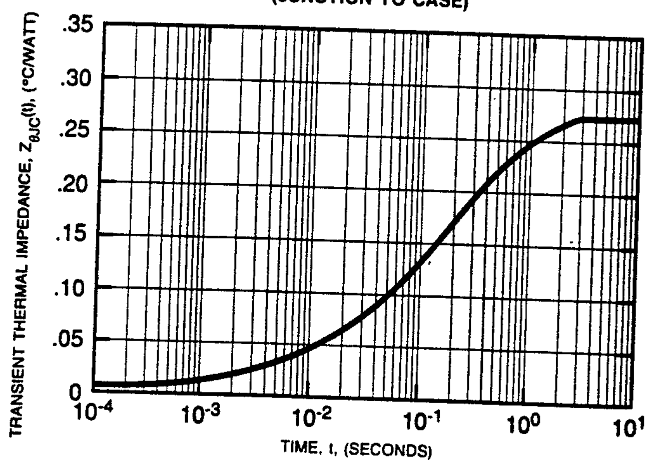
CD42 __ __ 90, CD47 __ __ 90
SCR/Diode POW-R-BLOK™ Modules
90 Amperes/100-1400 Volts

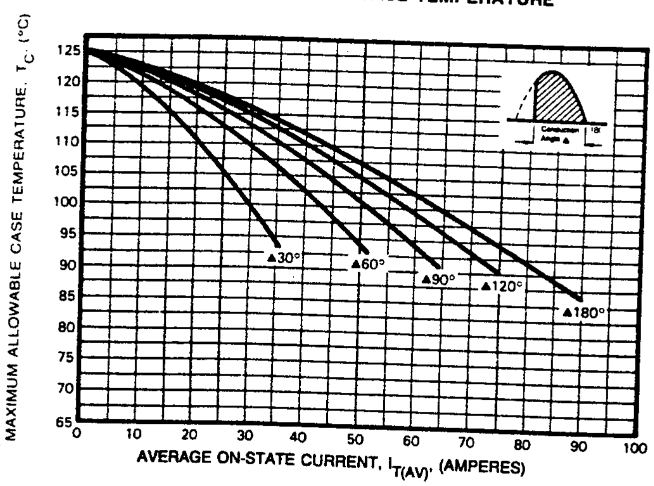
MAXIMUM ON-STATE CHARACTERISTICS



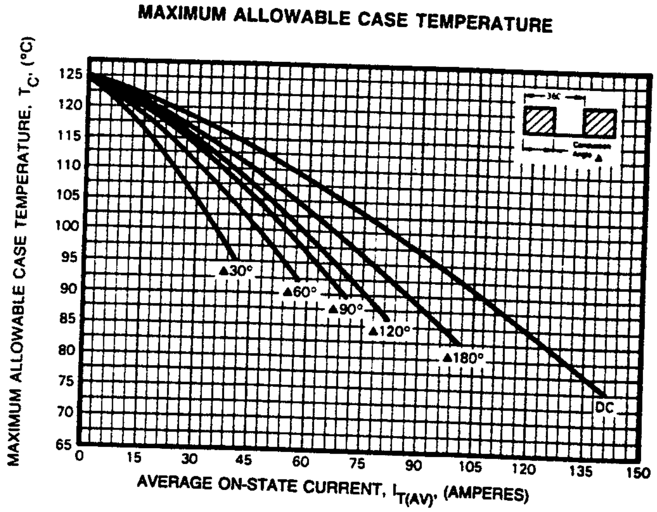
TRANSIENT THERMAL IMPEDANCE CHARACTERISTICS (JUNCTION TO CASE)



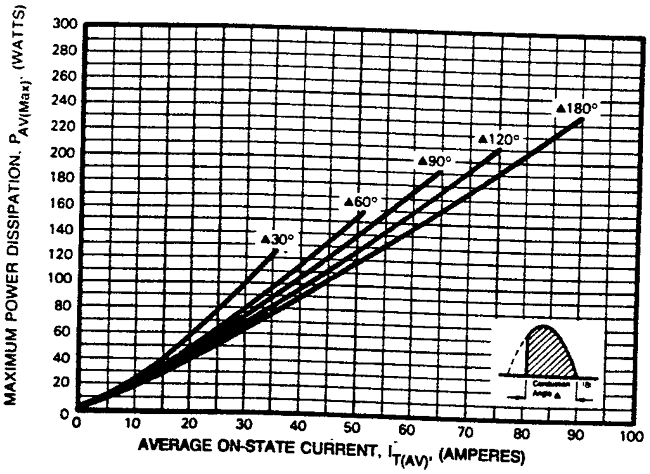
MAXIMUM ALLOWABLE CASE TEMPERATURE



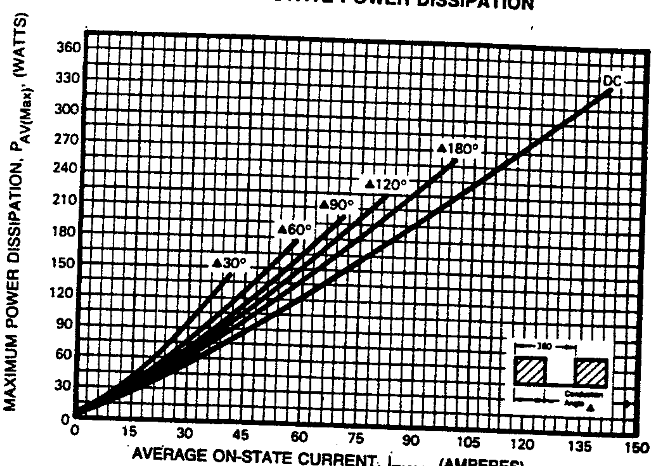
MAXIMUM ALLOWABLE CASE TEMPERATURE



MAXIMUM ON-STATE POWER DISSIPATION



MAXIMUM ON-STATE POWER DISSIPATION



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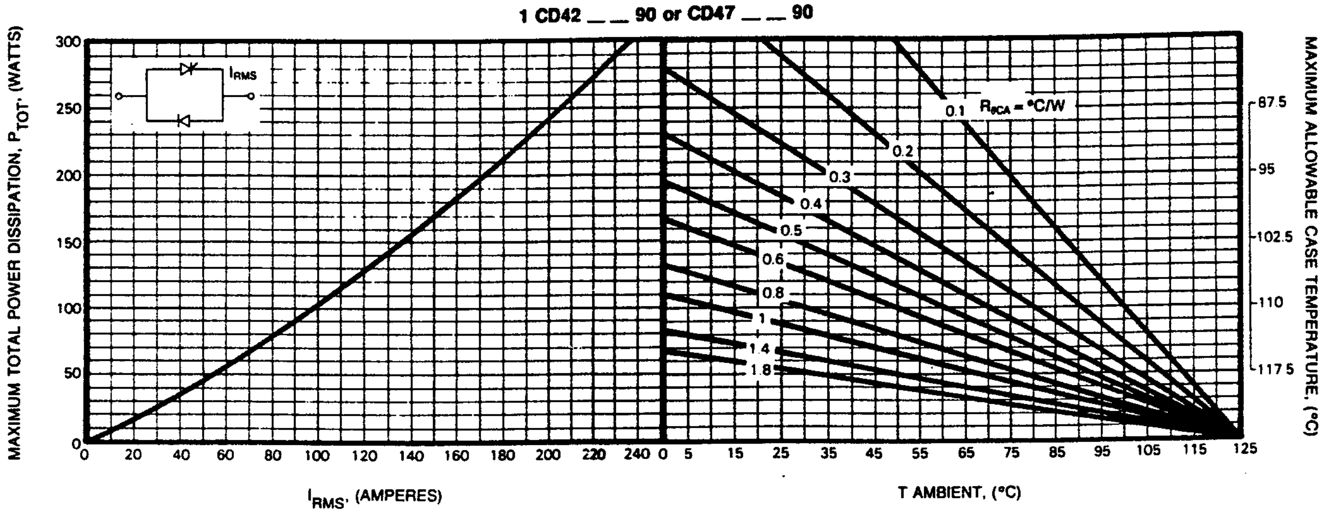
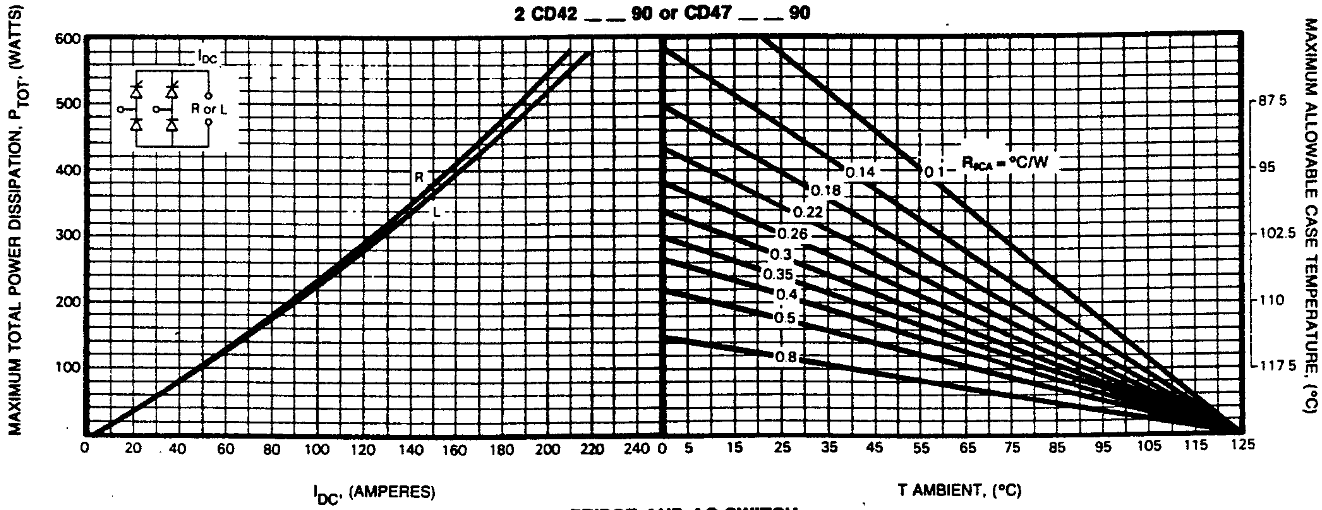
CD42 _ _ 90, CD47 _ _ 90
SCR/Diode POW-R-BLOK™ Modules
90 Amperes/100-1400 Volts

MAXIMUM TOTAL POWER DISSIPATION AND MAXIMUM AMBIENT TEMPERATURES

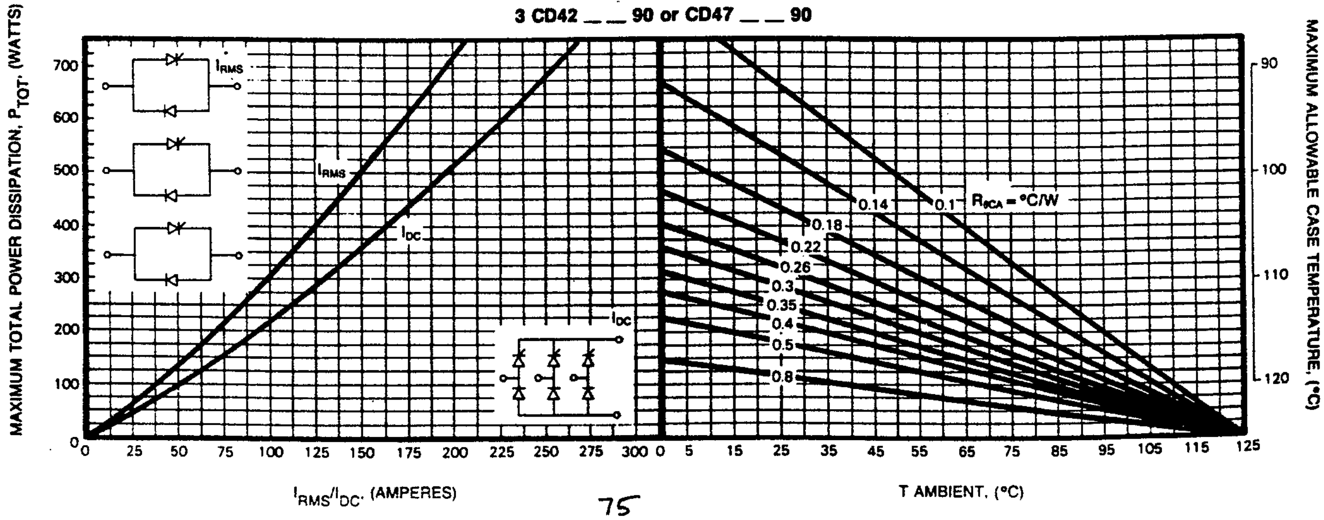
AC SWITCH
1 CD42 _ _ 90 or CD47 _ _ 90



1φ—BRIDGE RESISTIVE AND INDUCTIVE LOAD
2 CD42 _ _ 90 or CD47 _ _ 90



3φ—BRIDGE AND AC SWITCH
3 CD42 _ _ 90 or CD47 _ _ 90



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POW-R-BRIK™

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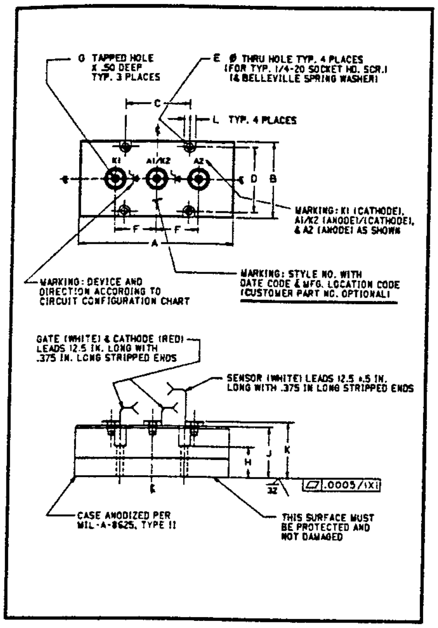
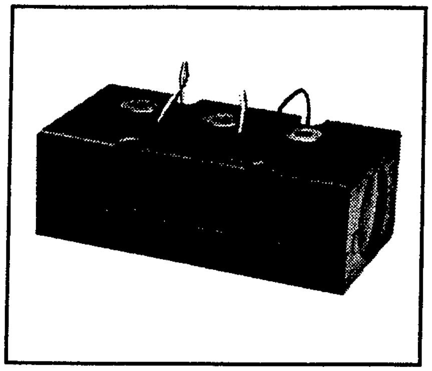
Phase Control Modules

345-800 Amperes/
400-3000 Volts





POW-R-BRIK™
Phase Control Modules
345-800 Amperes/400-3000 Volts

Description

Powerex POW-R-BRIK™ Modules are designed for medium and high current power control applications. POW-R-BRIK™ Modules feature an electrically isolated package that simplifies system packaging, installation and cooling. POW-R-BRIK™ Modules utilize Compression Bonded Encapsulation (CBE) mounting and double side cooling of the semiconductor elements. The Z7A outline POW-R-BRIK™ uses 33mm or 38mm elements and the Z9A outline POW-R-BRIK™ uses 50mm elements. Standard circuit configurations include Dual SCR, Dual Diode, SCR/Diode, and Diode/SCR. Additional circuit configurations, e.g. Single Element, Common Cathode, Common Anode, and special element types, e.g. Fast Switch SCRs, Fast Recovery Diodes GTOs and Transistors are available.

Features:

- ☐ Electrically Isolated Package
- ☐ Anodized Aluminum Housing
- ☐ Internal Copper Contacting
- ☐ Gold Element Contacting
- ☐ Internal Temperature Sensor
- ☐ Compression Element Contacting

Applications:

- ☐ AC Motor Starters
- ☐ DC Motor Controls
- ☐ Resistance Welding Controls
- ☐ Mining Power Centers
- ☐ High Voltage Motor Starters
- ☐ Transportation Systems

Ordering Information

Example: Select the complete thirteen digit module part number you desire from the Configuration Reference Description — i.e. P3Z7ACT700W16 is a 1600 Volt, 375 Ampere Average, Dual SCR POW-R-BRIK™ module with the standard thermistor.

POW-R-BRIK™ Modules
400-3000 Volts

Z7A Outline

Dim.	Inches	Metric
A	6.30	153.16
B	3.02	76.70
C	3.15	80.01
D	2.47	62.73
E	.328 ϕ	8.33 ϕ
F	1.83	46.48
G	5/16-18 UNC-2B	5/16-18 UNC-2B
H	1.27	32.25
J	2.09	53.08
K	2.25	57.15
L	.56	14.22

Z9A Outline

Dim.	Inches	Metric
A	7.50	190.5
B	3.70	93.98
C	3.15	80.01
D	3.15	80.01
E	.328 ϕ	8.33 ϕ
F	2.03	51.56
G	3/8-16 UNC-2B	3/8-16 UNC-2B
H	1.51	38.35
J	2.52	64.0
K	2.75	69.85
L	.56	14.22

Mounting bolt (E) torque limit is 11 ft./lbs.

Electrical terminal (G) torque limit is 11 ft. lbs. for type Z7A and 20 ft. lbs. for Z9A.

Apply a thin coating of thermal joint compound to heat sink surface prior to module mounting.

Module weights: Z7A weighs 6 lbs. while the Z9A module weighs 11 lbs.

If incoming tests are done for isolation voltage, the voltage should be applied in a slow manner rather than abruptly imposed on the device. The voltage should be applied between the top terminals, which must be shorted together, and the metal case.

The metal case is anodized and provides added voltage isolation capability if not damaged: factory hi-pot test is achieved without the benefit of the anodized coating.

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POW-R-BRIK™
Phase Control Modules
345-800 Amperes/400-3000 Volts

Maximum Ratings and Electrical Characteristics

	Voltage Gate Current, Speed of Element†														Isolation Voltage††		Strike Distance	
	Voltage					Gate		Current					Speed				Terminals	
Part Number	V_{DRM}/V_{RRM}① E1 (V)	E2 (V)	V_{RSM} E1 (V)	E2 (V)	dv/dt③① (V/µs)	V_{GT} (V)	I_{GT} (mA)	di/dt③④ (A/µs)	I_{DRM}/I_{RRM}① E1 (mA)	E2 (mA)	I_{TSM}/I_{FSM}⑤ E1 (kA)	E2 (kA)	SCR t_q (µsec)	Diode t_{rr} (µsec)	V_{RMS} (V)	I_{RMS} (mA)	To Case (Inches)	K_1/A_1 K_2/A_2 (Inches)
Diode/Diode																		
P1Z7AAR700W__ __	3000	3000	3100	3100	—	—	—	—	50	50	7	7	—	15	3000	1.1	.70	1.0
P1Z7ABR700W__ __	2200	2200	2300	2300	—	—	—	—	50	50	9	9	—	10	2500	.92	.70	1.0
P1Z9AAR900W__ __	3000	3000	3100	3100	—	—	—	—	150	150	16	16	—	20	3000	1.7	1.0	1.15
P1Z9ACR900W__ __	1200	1200	1300	1300	—	—	—	—	150	150	30	30	—	15	2500	1.5	1.0	1.15
P1Z9ADR900V__ __	600	600	700	700	—	—	—	—	150	150	50	50	—	10	2500	1.5	1.0	1.15
Half Control SCR/Rectifier ①																		
P2Z7ABB700W__ __	2200	2200	2300	2300	300	3	150	600	30	30	9	9	150	10	2500	.92	.70	1.0
P2Z7ACB700W__ __	1600	1600	1700	1700	300	3	150	600	30	30	10	14	150	8	2500	.92	.70	1.0
P2Z9AAA900W__ __	3000	3000	3100	3100	300	3	200	600	150	150	15	16	400	20	3000	1.7	1.0	1.15
P2Z9ABA900W__ __	2200	2200	2300	2300	300	3	200	600	75	75	17	16	250	20	2500	1.5	1.0	1.15
P2Z9ACA900W__ __	1600	1600	1700	1700	300	3	200	600	75	75	25	16	150	20	2500	1.5	1.0	1.15
Full Control SCR/SCR																		
P3Z7ABT700W__ __	2200	2200	2300	2300	300	3	150	600	30	30	9	9	150	—	2500	.92	.70	1.0
P3Z7ACT700W__ __	1600	1600	1700	1700	300	3	150	600	30	30	10	10	150	—	2500	.92	.70	1.0
P3Z7AAT800W__ __	3000	3000	3100	3100	300	3	150	600	35	35	9	9	200	—	2500	.92	.70	1.0
P3Z7ABT800W__ __	2200	2200	2300	2300	300	3	150	600	35	35	12	12	200	—	2500	.92	.70	1.0
P3Z7ACT800W__ __	1400	1400	1500	1500	300	3	150	600	35	35	15	15	200	—	2500	.92	.70	1.0
P3Z9AAT900W__ __	3000	3000	3100	3100	300	3	200	600	150	150	15	15	400	—	3000	1.7	1.0	1.15
P3Z9ABT900W__ __	2200	2200	2300	2300	300	3	200	600	75	75	17	17	250	—	2500	1.5	1.0	1.15
P3Z9ACT900W__ __	1600	1600	1700	1700	300	3	200	600	75	75	25	25	150	—	2500	1.5	1.0	1.15
Half Control Rectifier/SCR ⑥																		
P7Z7ABB700W__ __	2200	2200	2300	2300	300	3	150	600	30	30	9	9	150	10	2500	.92	.70	1.0
P7Z7ABC700W__ __	1600	1600	1700	1700	300	3	150	600	30	30	14	10	150	8	2500	.92	.70	1.0
P7Z9AAA900W__ __	3000	3000	3100	3100	300	3	200	600	150	150	16	15	400	20	3000	1.7	1.0	1.15
P7Z9AAB900W__ __	2200	2200	2300	2300	300	3	200	600	75	75	16	17	250	20	2500	1.5	1.0	1.15
P7Z9AAC900W__ __	1600	1600	1700	1700	300	3	200	600	75	75	16	25	150	20	2500	1.5	1.0	1.15

†Element location indicated by E1 or E2.
††Hi-Pot. 60 Hz, 1 minute test

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POW-R-BRIK™
Phase Control Modules
345-800 Amperes/400-3000 Volts

Part Number	Current and Thermal Ratings of Module: Current			Thermal					Circuit Currents ③: Units Per Sink→	1	3	2	3	Element Data Model*	
	$I_{T(av)}$ ① (A)	@T_C (°C)	Maximum Power Dissipation (W)	T_J (°C)	Sensor @T_J (Ω)	$R_{\theta JC}$ per Module (°C/W)	$R_{\theta CS}$ per Module ⑦ (°C/W)	$R_{\theta CA}$ (°C/W)	T_A (°C)	AC Switch I_{RMS} (A)	AC Switch ⑨ I_{RMS} (A)	1φ Bridge I_{DC} (A)	3φ Bridge ⑨ I_{DC} (A)	E1	E2
Diode/Diode															
P1Z7AAR700W __ __	355	105	1125	150	315	.04	.01	.10	40	—	—	385	400	AR7	AR7
P1Z7ABR700W __ __	435	105	1125	150	315	.04	.01	.10	40	—	—	440	465	BR7	BR7
P1Z9AAR900W __ __	590	105	1500	150	315	.03	.008	.08	40	—	—	570	600	AR9	AR9
P1Z9ACR900W __ __	740	105	1500	150	315	.03	.008	.08	40	—	—	670	705	CR9	CR9
P1Z9ADR900V __ __	800	110	1330	150	315	.03	.008	.08	40	—	—	775	805	DR9	DR9
Half Control SCR/Diode ⑧															
P2Z7ABB700W __ __	380	85	1100	130	530	.04	.01	.10	40	560	275	330	350	BT7	BR7
P2Z7ACB700W __ __	395	85	1100	130	530	.04	.01	.10	40	590	290	345	365	CT7	BR7
P2Z9AAA900W __ __	430	85	1325	125	640	.03	.008	.08	40	630	310	370	390	AT9	AR9
P2Z9ABA900W __ __	520	85	1465	130	530	.03	.008	.08	40	740	365	435	460	BT9	AR9
P2Z9ACA900W __ __	590	85	1465	130	530	.03	.008	.08	40	800	385	470	495	CT9	AR9
Full Control SCR/SCR															
P3Z7ABT700W __ __	345	85	1095	130	530	.04	.01	.10	40	505	250	300	315	BT7	BT7
P3Z7ACT700W __ __	375	85	1095	130	530	.04	.01	.10	40	550	270	320	335	CT7	CT7
P3Z7AAT800W __ __	300	85	1095	130	530	.04	.01	.10	40	445	220	255	265	AT8	AT8
P3Z7ABT800W __ __	390	85	1095	130	530	.04	.01	.10	40	560	275	330	345	BT8	BT8
P3Z7ACT800W __ __	450	85	1095	130	530	.04	.01	.10	40	630	300	385	405	CT8	CT8
P3Z9AAT900W __ __	355	85	1295	125	640	.03	.008	.08	40	535	260	310	330	AT9	AT9
P3Z9ABT900W __ __	470	85	1460	130	530	.03	.008	.08	40	675	335	400	420	BT9	BT9
P3Z9ACT900W __ __	600	85	1460	130	530	.03	.008	.08	40	815	375	460	480	CT9	CT9
Half Control Diode/SCR ⑧															
P7Z7ABB700W __ __	380	85	1100	130	530	.04	.01	.10	40	560	275	330	350	BR7	BT7
P7Z7ABC700W __ __	395	85	1100	130	530	.04	.01	.10	40	590	290	345	365	BR7	CT7
P7Z9AAA900W __ __	430	85	1325	125	640	.03	.008	.08	40	630	310	370	390	AR9	AT9
P7Z9AAB900W __ __	520	85	1465	130	530	.03	.008	.08	40	740	365	435	460	AR9	BT9
P7Z9AAC900W __ __	590	85	1465	130	530	.03	.008	.08	40	800	385	470	495	AR9	CT9

① Applies for zero or negative gate bias.
② Higher dv/dt ratings available, consult factory.
③ With recommended gate drive.
④ Per JEDEC standard RS-397, 5.2.2.6.
⑤ Per JEDEC RS-397, 5.2.2.1.
⑥ Bottom side cooled.
⑦ Consult recommended mounting procedures.
⑧ Designs are available for "Current Source Inverter" applications, consult factory.
⑨ Reflects substantial derating necessary with single .08°C/W or .10°C/W sink.

*Reference element data model on page 448.

POWEREX

Powerex, Inc., Hillis Street, Youngwood, Pennsylvania 15697 (412) 925-7272
Powerex Europe, S.A., 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 72.75.15

POW-R-BRIK™
Phase Control Modules
345-800 Amperes/400-3000 Volts

Element Code Reference

Element Code	Element Type	Comparable Disc Device	Available Voltage Range	Coefficients for V_{TM}, V_F Model①② A	B	C	D
AR7	33mm Diode	R7S0 _ _ 08XX00	2200-3000	.89605	-.08108	.00045	.02836
BR7	33mm Diode	R7S0 _ _ 12XX00	1200-2200	.63200	-.02192	.00013	.02065
CR7③	33mm Diode	R7S0 _ _ 16XX00	800-1200	.45000	.02800	.00008	.01128
AR9	50mm Diode	R9G0 _ _ 12XX00	2200-3000	.39964	.05540	.00024	.00319
CR9	50mm Diode	R9G0 _ _ 18XX00	800-1200	.60627	-.00168	.00005	.00766
DR9	50mm Diode	R9G0 _ _ 22XX00	400- 800	.46319	.02950	.00006	.00061
BT7	33mm SCR	T7S0 _ _ 6504DN	1400-2200	.74419	.00380	.000325	.01882
CT7	33mm SCR	T7S0 _ _ 7504DN	800-1600	.58729	.06654	.000416	.00060
AT8	38mm SCR	T820 _ _ 6003DH	2200-3000	1.02841	.13475	.001179	-.03631
BT8	38mm SCR	T820 _ _ 7503DH	1200-2200	.88287	-.07743	.00010	.03081
CT8	38mm SCR	T820 _ _ 9003DH	800-1400	1.08412	-.13881	-.00013	.03756
AT9	50mm SCR	T9G0 _ _ 0803DH	2200-3000	1.43303	-.10092	.000620	.01789
BT9	50mm SCR	T9G0 _ _ 1003DH	1200-2200	.96195	-.08755	.000074	.03286
CT9	50mm SCR	T9G0 _ _ 1203DH	800-1600	.55570	.05740	.000135	.00104
9HP③	50mm SCR	T9GH _ _ 0903DH	1200-2200	.95642	-.00285	.000225	-.00178

① V_{TM}, V_F = A + B x LN(I) + C x I + D x $\sqrt{I}$ (I = Amps Peak)
② Coefficients are for T_J = 130°C, 50A through 3000A Peak
③ Module ratings for these elements are not shown, consult factory.

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POW-R-BRIK™
Phase Control Modules
345-800 Amperes/400-3000 Volts

Configuration Reference

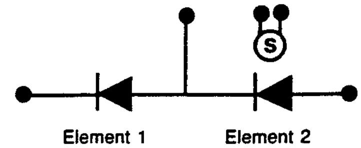
The POW-R-BRIK™ part number system takes the form *P3 Z7A CT7 00 W16* where:

- *P3* is the configuration number. The configurations are shown pictorially in the right hand column.
- *Z7A* is the package type per the outline drawings Z7A and Z9A on the first page of this data sheet.
- *CT7* denotes the element code. The Element Code Reference on page 448 provides information on the standard element codes, including the corresponding disc device using the element. Refer to the appropriate disc package data sheets in the Powerex Semiconductor Data Book for additional device specifications.
- *00* denotes special features:
  00 — module includes standard thermistor
  XT — no thermistor
  AA-ZZ — denotes unique customer specification
- *W16* denotes voltage code per the table below. Note that not all voltage ratings are available for every element. Refer to the Element Code Reference for available voltage ranges for a given element.

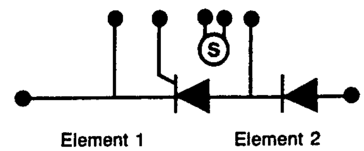
Elements Voltage Rating	Voltage Code
400	V04
600	V06
800	V08
1000	W10
1200	W12
1400	W14
1600	W16
1800	W18
2000	W20
2200	W22
2400	W24
2600	W26
2800	W28
3000	W30

Circuit Configurations

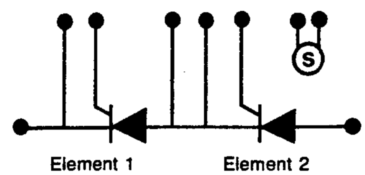
P1 — DIODE
P4 — FAST DIODE*



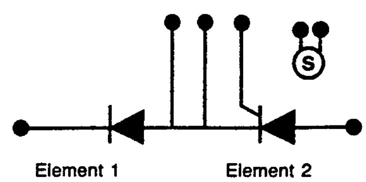
P2 — SCR/DIODE
P5 — FAST SCR/FAST DIODE*



P3 — SCR/SCR
P6 — FAST SCR/FAST SCR*



P7 — DIODE/SCR
P8 — FAST DIODE/FAST SCR*



*Consult Factory for Available Ratings.

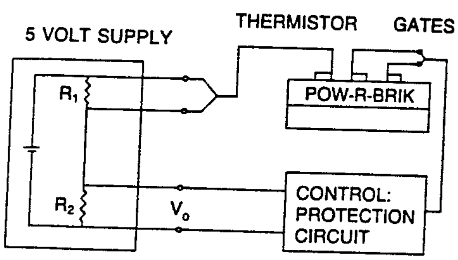
POWEREX

Powerex, Inc., Hillis Street, Youngwood, Pennsylvania 15697 (412) 925-7272
Powerex Europe, S.A., 428 Avenue G. Durand, BP107, 72003 Le Mans, France (43) 72.75.15

POW-R-BRIK™
Phase Control Modules
345-800 Amperes/400-3000 Volts

Typical Thermistor Circuit

Thermistor temperatures can be measured using the following circuit arrangement in conjunction with a 5 volt source. Resistance values for R_1 and R_2 are specified for two operating temperature ranges.



1. Temperature range, 75°C through 125°C
   R_1 = 3.5K ohms
   R_2 = 840 ohms
   V_0 = 2.5 volts at 100°C
2. Temperature range, 90°C through 140°C
   R_1 = 2.2K ohms
   R_2 = 500 ohms
   V_0 = 2.45 volts at 115°C

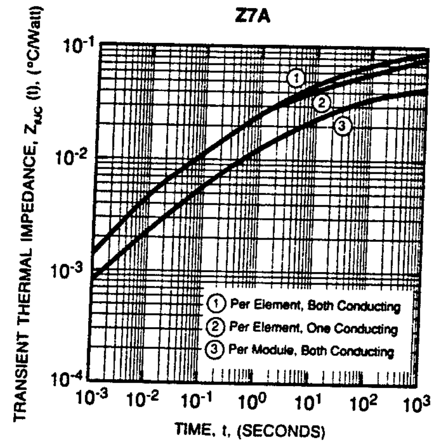
The output signal (V_0) is approximately 30 mv/°C over the temperature range indicated.

POW-R-BRIK™ Thermistor Characteristics

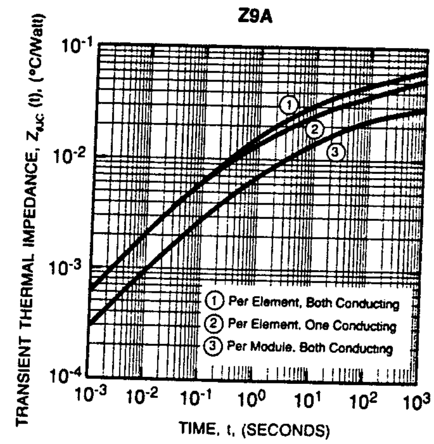
Thermistor Resistance Ohms ①	Thermistor Temperature °C ②	Element Average Temperature Steady State °C (Min.) ③	Element Average Temperature Dynamic °C (Max.)
12,093	40	43	50
7,337	50	53	60
4,990	60	63	70
3,324	70	73	80
2,262	80	83	90
1,569	90	93	100
1,316	95	98	105
1,109	100	103	110
938	105	108	115
797	110	113	120
680	115	118	125
582	120	123	130
500	125	128	135
431	130	133	140

① Curve matched ±2% over temperature range of +40°C to +125°C. Resistance tolerance specified at +125°C, ±6%.
② Without self heating, 10 mW maximum thermistor dissipation.
③ Use "Sensor at T_J" ohms from characteristics for recommended steady state overload trip resistance.

TRANSIENT THERMAL IMPEDANCE CHARACTERISTICS (JUNCTION TO CASE)
Z7A



TRANSIENT THERMAL IMPEDANCE CHARACTERISTICS (JUNCTION TO CASE)
Z9A



Appendix E

THE 476200 - 477000
BONDED FIN AIR COOLED HEAT SINKS

The precision fit and thermal epoxy bonding of aluminum fins provide more effective cooling surface per cubic inch of space than is possible with extruded or cast heat sinks.

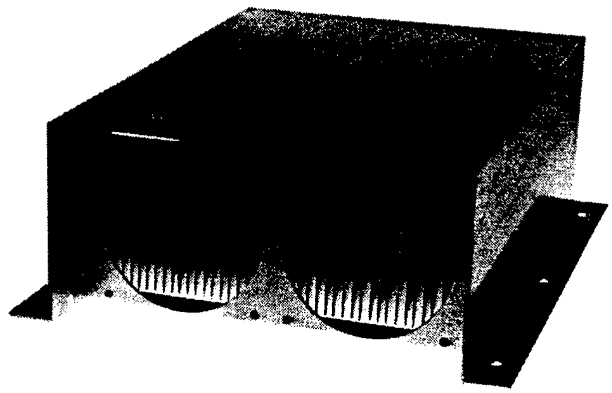
The high performance bonded fin heat sinks provide exceptionally low thermal resistances in both natural and forced convection applications.

These heat sinks provide an ideal mounting surface for semiconductor power modules.

Note: *To order "muffin" fans use the following codes in the 9th & 10th positions:
11 = One Fan
22 = Two Fans
The 8th position is reserved for pads (see pages 14 - 16).

Design Features

- Bonded fin and flat mounting surface design provide optimum cooling of multiple power modules for improved reliability and performance.
- Lightweight, reliable and rugged field proven epoxy bonded fin construction.
- Standard lengths designed to accomodate multiple mounting of industry standard power modules.
- Mounting hole patterns available for all standard modules, consult customer service department for further information.
- Simple device assembly and field replacement.
- Forced air models designed to accept standard "muffin" fan (4.12 x 4.12 mounting hole pattern).*
- Natural convection models available with or without 1" wide mounting flanges.
- Available unfinished (U) or with gold chromate(C) finish, indicate the appropriate ordering code in the 7th position.
- Bonded fin technique provides extreme flexibility for custom design applications.



Forced Convection Models

Model	Fig	Dim A	Dim B	Dim C	Dim D	Dim E	Dim F	°C/W
476200	1	7.0"	9.50"	3.75"	7.28"	6.0"	4.78"	0.080
476300	1	12.0"	14.50"	6.25"	7.28"	6.0"	4.78"	0.060
476400	2	12.0"	14.59"	6.00"	13.28"	12.0"	10.78"	0.028
476500	2	14.0"	16.59"	7.00"	13.28"	12.0"	10.78"	0.025
476600	2	16.0"	18.59	8.00"	13.28"	12.0"	10.78"	0.024

Natural Convection Models

Model	Flanges	Dim A	Dim B	°C/W
476700	Straight	7.0"	2.500"	0.30
476800	Straight	12.0"	5.000"	0.22
476900	Angle	7.0"	2.500"	0.30
477000	Angle	12.0"	5.000"	0.22

Forced Convection

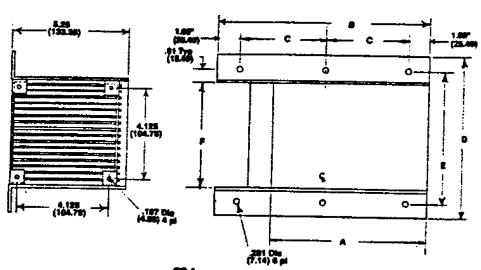


FIG. 1

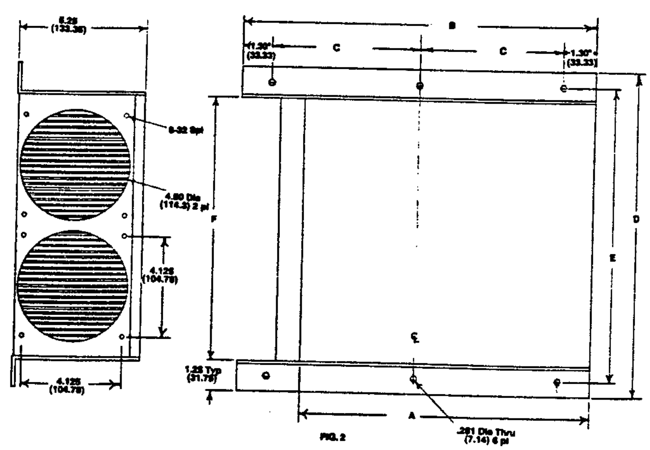
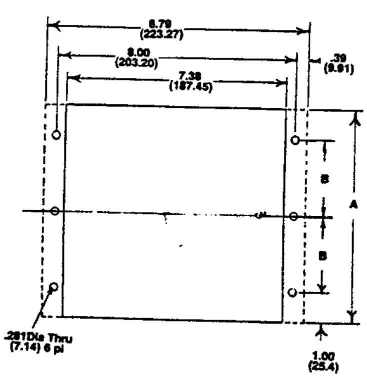
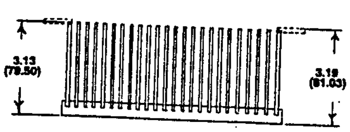


FIG. 2

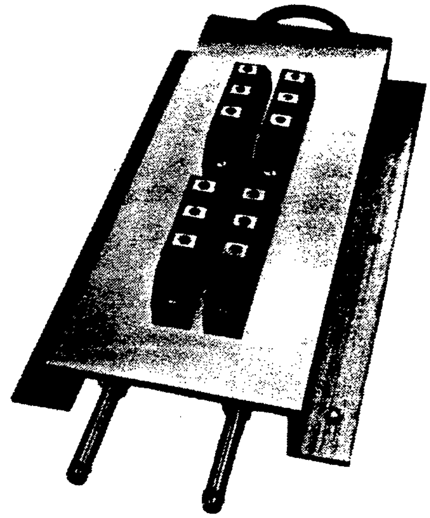
Natural Convection





HIGH POWER

THE 417801 - 418301
LIQUID COOLED COLD PLATES



Designed for use with standard or custom power semiconductors in heavy load application where air cooling techniques are impractical or inadequate.

The cold plates are standard without semiconductor hole patterns. Aavid can provide standard or custom hole patterns, complex CNC machining or electrical isolation along with engineering assistance for custom applications.

Specifications

Size - 5" wide mounting surface, 1 1/2" overall height.

Length - Standard 7", 12" and 24" or custom lengths.

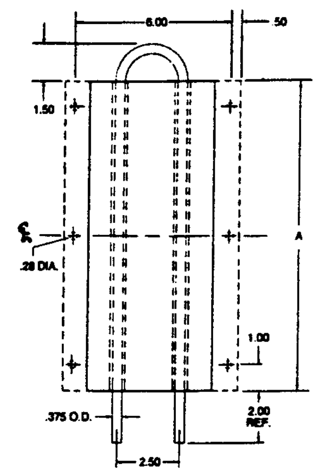
417801, 417901 and 418001 include 1" wide mounting flanges with 0.28" dia. through holes.

418101, 418201 and 418301 do not include mounting flanges.

Available unfinished (U) or with gold chromate finish (C),

- Indicate appropriate ordering code in the 7th position.

Copper coolant tubing is mechanically locked and epoxy sealed to the bottom of the cold plate. This technique seals out moisture and other corrosives while providing an excellent thermal path from cold plate to cooling fluid.



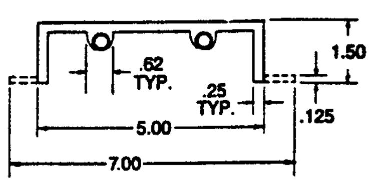
Materials

Plate - 6063-T5 Aluminum Extrusion.

Tube - Standard, 0.375" O.D. x 0.032 Wall C 12200(DHP) Copper, 1/4-1/2 hard.

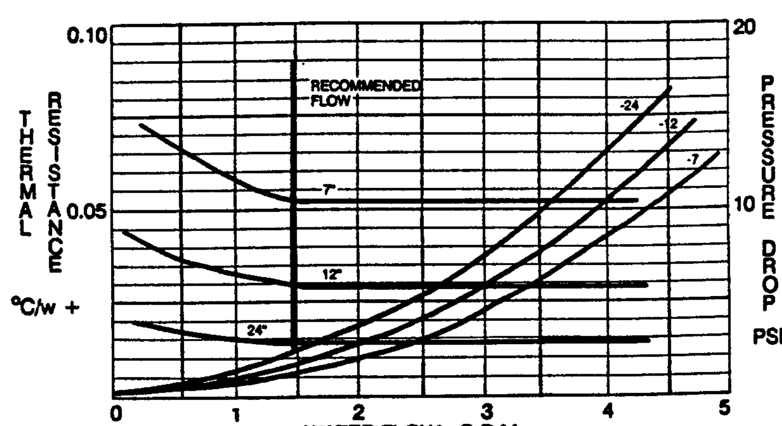
- Tube also available in stainless steel, to order stainless steel indicate 2 in the 6th positions i.e. 418002U.

Epoxy - aluminum filled, high thermal conductivity.



	Model	Dim A
Models with mounting flanges	417801U	7.0"(177.9)
	417901U	12.0"(304.8)
	418001U	24.0"(609.6)
Models without mounting flanges	418101U	7.0"(177.9)
	418201U	12.0"(304.8)
	418301U	24.0"(609.6)

PERFORMANCE CHARACTERISTICS



SERIES 440000 & 450000 ISOLATED HEAT SPREADERS FOR PRESSURE MOUNTED SEMICONDUCTORS

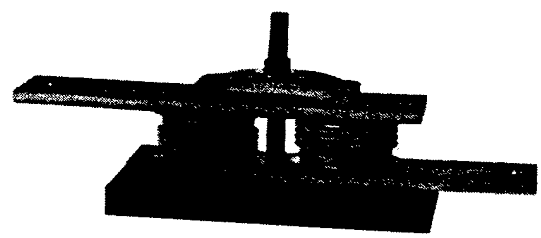
Isolated Heat Spreaders, of "open brick" construction, for high power rectifiers, SCR's and GTO's up to 1" thick are part of a new family of electrically isolated, thermally conducting assemblies designed for low cost, thermally efficient multiple device heat sink applications. Several Isolated Heat Spreaders may be mounted to a common heat sink for improved overall system efficiency.

Specifications

- Series 440000 has four 3/8-16 x 0.38" deep mounting holes in the bottom of a 2" x 4.5" electrically isolated base plate.
- Series 450000 has four counter bored holes for 1/4-20 cap screws in the top of a 3" x 6.28" electrically isolated base plate.
- Model 441100 and model 451100 are designed for AC switch and other common power (buss) applications.
- Model 442100 and model 452100 are designed for voltage doublers and other split power (buss) applications.
- Bottom bus bars are available with straight or 30° power tangs.
- Top bus bars are available with straight, 30° or 90° power tangs.

Key Features

- Rapid assembly.
- Easy device replacement.
- Built-in dielectric isolation (2500 VAC RMS).
- Low thermal impedance.
- High reliability.
- UL listed.



Part Number

- 1st position: 4 - a fixed digit.
- 2nd position: 4 for bottom mount, 5 for top mount.
- 3rd position: 1 for single bottom buss, 2 for split bottom buss.
- 4th position: 1 - single width (consult Aavid's customer service department for double and triple width information).
- 5th position: Top angle - 0 for 0°, 3 for 30°, 9 for 90°.
- 6th position: Bottom angle - 0 for 0°, 3 for 30°.
- 7th position: Enter (F).

To Order: Use the above part number listing to compose the customized Isolated Heat Spreader to meet your thermal requirements.

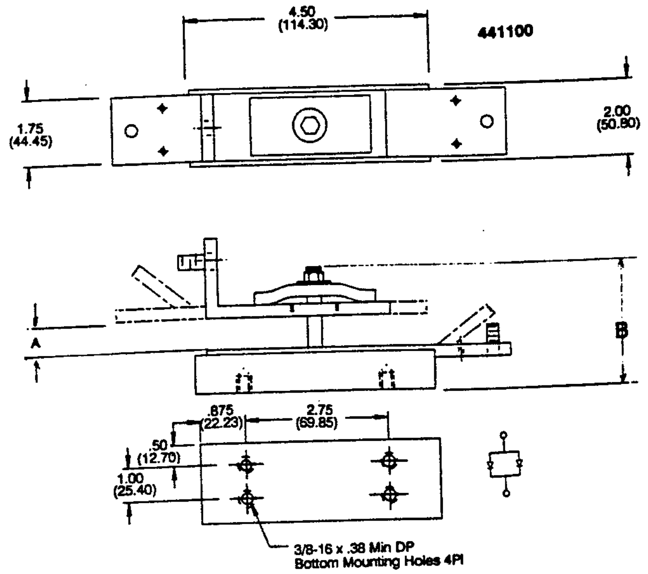
Construction

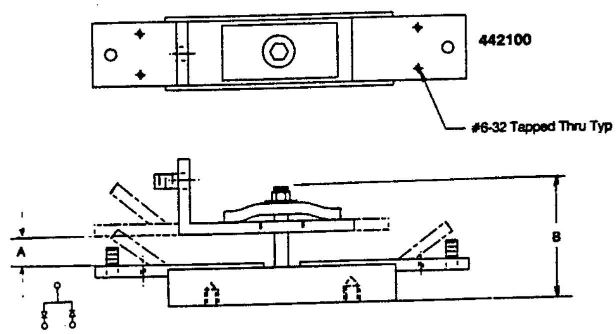
- Spring bar - Zinc plated tempered steel.
- Power buss - Unfinished aluminum.
- Base - Epoxy coated aluminum (mounting surface unfinished.)

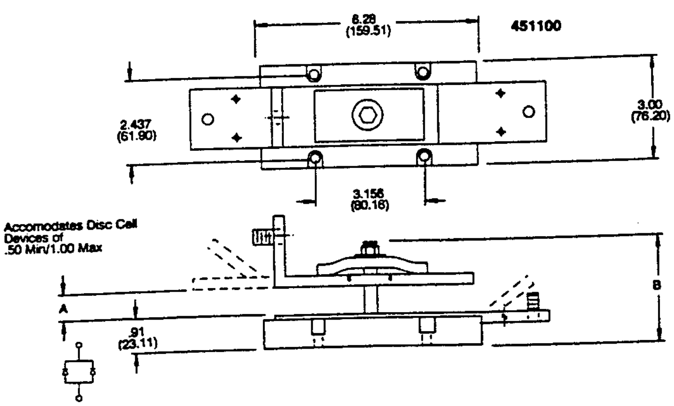
 One Kool Path, P.O. Box 400, Laconia, NH 03247 Tel 603-528-3400, FAX 603-528-1478, TWX 510-298-1127

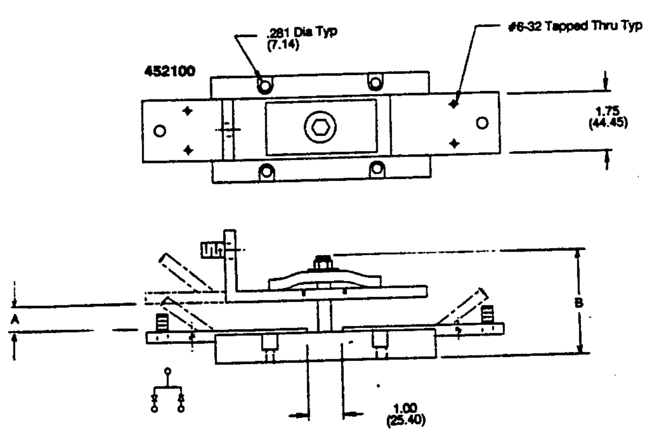
ISOLATED HEAT SPREADERS

Dim A Min. 0.500"Ref (12.70)	Dim A Max 1.00" Ref (25.40)	Dim B 3.25"Ref (82.55)









Holes are standard. Studs 5/16"-18 x .875 long are available as an potion - contact our customer service department.

Appendix F

Spray Oil-Cooled Motors for High Speed Industrial Applications

by
G. H. Seffernick, Senior Design Engineer
Westinghouse Electric Corporation
Electrical Systems Division

A new line of high speed industrial motors, described in conceptual form, offers dramatic reductions in size and weight. The small size and excellent cooling allow 24,000 RPM, 200 HP motors to be built with standard squirrel cage construction and used at speeds up to 28,500 RPM without mechanical stress damage in the rotor due to centrifugal force. These advantages are the result of conduction and spray oil-cooling technology, developed for the aerospace industry, whereby the cooling oil flows around the motor magnetic iron and is sprayed directly onto the heat producing components.[1-4]. This results in low temperature difference between the coolant and heat sources which, in turn, permits the motor to be operated at higher power densities and at reduced speeds without overheating the insulation system. The impact this has on motor weight is illustrated in Figure 1. The air-cooled machines listed in Figure 1 are Westinghouse Life-Line T 3600 RPM induction motors. The spray oil-cooled induction motors listed in Figure 1 are designed for operation at 24,000 RPM.

Many industrial applications including fans, pumps, turbine compressors, machine tools, vehicle drives and test stands require operation at speeds up to 28,000 RPM. These applications are areas where high variable frequency AC inverter and electric motor drives can often replace the present combination of a constant speed motor and speed increaser, usually with significant energy savings. Direct drive hermetically sealed spray oil-cooled induction motors are especially well suited for high speed applications because of simple rugged construction, low rotor inertia, environment free operation, high reliability, small size and low weight.

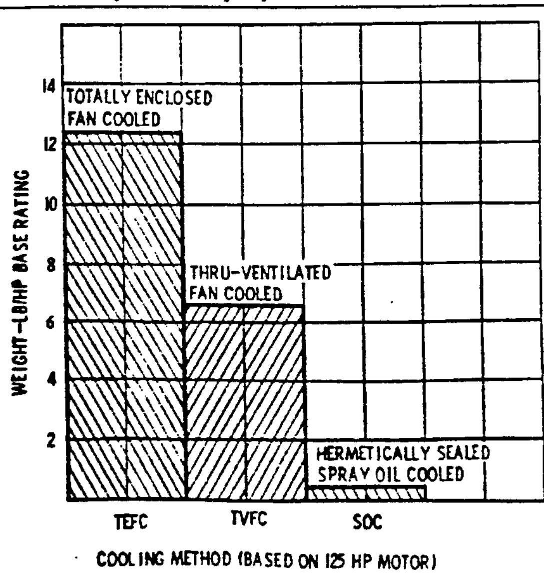


FIGURE 1. Dramatic reduction in weight/unit of rating is illustrated by comparing air-cooled industrial motors with high-performance spray oil-cooled motors. Data is based on 125 HP motors.

TEFC - Totally enclosed fan cooled Westinghouse Life-Line T 3600 RPM motor

TVFC - Thru-ventilated fan cooled Westinghouse Life-Line T 3600 RPM motor

SOC - Hermetically sealed spray oil-cooled Westinghouse 24,000 RPM motor

Historically, the price of the AC inverter and motor has been more expensive than a constant speed motor plus speed increaser. Technological developments in microprocessors and power switching devices have significantly reduced the price of an AC inverter drive. Current estimates indicate that market prices will be reduced to one half of their present levels and these economical variable frequency (up to 400 Hz) inverter drives will be commercially available in sizes of at least 200HP in 1 to 5 years.

The ability to direct drive the machinery at speeds up to 28,000 RPM will yield cost improvements in the overall system design. These savings include material savings due to reduced motor size and completely eliminating the gear box and energy savings through speed regulation to match the load demand and low maintenance cost.

EVOLUTION OF MOTOR COOLING One of the fundamental problems associated with high speed motor operation is cooling. Motors designed for industrial applications used forced air-cooling, but it has severe limitations. Air has low specific heat and low density and therefore a low heat transfer coefficient. Since the motor output power is the product of torque and speed and the motor size is determined by rated torque, it is obvious that as the output speed of the motor is increased, the size of the motor decreases for a given horsepower. The reduced motor volume and surface area then make it harder to cool the motor when operating with the same loss. An increase in motor size may be necessary to allow for enough cooling passages to insure accessibility to the hot spots and to cool the motor to a safe operating temperature.

An air-cooled variable speed electric motor operated at a reduced speed loses the effectiveness of the motor cooling fan since the air capacity (CFM) varies directly with the fan

(continued on following page)

Spray Oil-Cooled Motors

(continued from preceding page)

speed. However, if the voltage and frequency are adjusted for constant torque at the reduced speed, the electrical copper losses will not change. Therefore, the motor size must be designed large enough to cool the motor when operating at the reduced speed. A larger fan will reduce the efficiency of the motor, under high speed operation, since the power required to drive the fan varies as the cube of the speed.

The squirrel cage rotor construction, though very rugged, has a maximum speed and size at which it can be operated without mechanical damage due to centrifugal force. If the maximum allowable rotor stress is exceeded, it becomes mandatory to reduce the mechanical stress to a safe value by decreasing the rotor diameter. This implies an increase in stack length since the rotor size cannot be decreased below the volume required to produce the rated torque without saturation of the magnetic circuit. Longer stack lengths are limited by critical speed considerations. High strength materials and special fabrication techniques can be selected to increase, within limits, the maximum allowable rotor speed but not without an increase in cost.

Experience has shown that the maximum rating of a fan air-cooled induction motor designed for a constant speed of 24,000 RPM is about 43 HP for a thru-ventilated construction and about 19 HP for a totally enclosed construction. This is the maximum size that can be fan air-cooled without exceeding the maximum allowable rotor speed using commercially available high strength materials and fabrication techniques.

These limitations in power ratings can be overcome by using existing spray oil-cooling technology developed by Westinghouse and others for aircraft and ground vehicle applications. Westinghouse experience in the design, development and application of high speed oil-cooled rotating electric equipment dates back to the early 1950s when, due to the severe operating conditions of the B-58 aircraft electrical generator application, air-cooling was impractical. This resulted in the development of a conduction oil-cooled generator.

During the development of the B-58 cooling system, internally wetted designs (spray oil and flooded oil systems) were also investigated. Because suitable high temperature insulation materials available at the time were fibrous and would disintegrate and contaminate the oil, it was necessary to keep the oil separate from the generator windings.

Conduction cooling is achieved by circulating the oil through closed passages around the stator magnetic iron and through the rotor shaft and then to a heat exchanger. Oil is a much better coolant than air because the specific heat is double and much greater mass flow rates can be obtained. However, since the oil is contained in passages, there is a thermal conductive path between the heat-generating components and the coolant. This path, while short, must necessarily be across interface joints, airgaps and through electrical insulation materials which causes the total temperature differential between the winding hot spot and the cooling oil to be high.

With the introduction of high temperature, fluid resistant film insulation such as DuPont ML enamel and Kapton sheet, Westinghouse Doryl varnish, etc., internally wetted systems became feasible. A detailed, planned program for the development of direct oil-cooling by internal spray techniques was implemented in 1967. Each step of the development has provided essential information from which significant refinements in spray oil-cooling techniques, mechanical construction, and electromagnetic design have been achieved. As a result, the state-of-the-art technology in spray oil-mist-cooling was advanced to include high speed (13,000 to 28,000 RPM) motors and generators.

Since the oil, which has good heat capacity and heat transfer capability, is sprayed directly on the sources of heat the temperature rise is low. Spray oil-cooling combined with conduction cooling is so effective that, with proper voltage and frequency adjustment, a high speed motor can be operated in a hostile environment at a speed near 0 RPM with rated torque load.

FUNDAMENTAL MOTOR CHARACTERISTICS Cooling and critical rotor speed are not the only limiting factors in variable high speed operation of polyphase induction motors. AC inverter drives can be designed with the capacity of controlling voltage magnitude, frequency and rate of change. Automatic control and feedback circuits can be added to the power inverter for independent voltage magnitude and frequency adjustments to limit motor starting current for smooth motor speed acceleration and deceleration and for operation at optimum efficiency, power factor and speed with load torque changes. With this much flexibility, limitations such as magnetic saturation and output torque capabilities must be considered to avoid premature failure and uneconomical operation.

The maximum torque of a polyphase induction motor is determined largely by leakage reactance and will vary as the square of the flux density in the air gap. Saturation of the magnetic circuit limits the magnetic flux density in the air gap. Since the maximum torque is determined by the air gap flux density, saturation of the magnetic circuit limits the maximum torque of the machine. When the magnetic circuit begins to saturate more excitation current (which is a highly lagging current) is required to produce the required flux. Hence the power factor is reduced and the stator copper and core loss are increased. If the magnetic circuit becomes too highly saturated the motor will overheat and the power factor will be unacceptably low. Since the flux density varies directly with the primary voltage magnitude and inversely with the frequency, the primary voltage must be controlled on a constant volts per hertz basis to avoid magnetic saturation.

Constant torque, from start to maximum speed, is a common mode of operation for an AC inverter and induction motor drive. To maintain torque capability, the air gap flux density must be maintained as the frequency is adjusted. Primary voltage must be controlled on a constant volts per hertz basis. The rated voltage, frequency, current and primary hot resistance are used to calculate the volts/hertz constant. Since the line current is the same at all motor speeds, the primary resistance voltage drop will be a constant magnitude at any frequency with a constant load torque. In other words, the input phase voltage will be made up of a constant primary resistance voltage drop and the primary voltage which will vary with frequency. At high frequencies the primary resistance voltage drop is small compared to the input voltage and can be neglected.

A motor operating at a constant torque load, with the voltage and frequency adjusted for a constant phase

current, has the same slip speed at all operating speeds including start. A family of speed-torque curves is obtained with the curves parallel to one another as illustrated in Figure 2. As the frequency is reduced, the stable operating portion of the speed torque curve occurs at lower and lower speeds, until full load torque with rated phase current occurs at start. The optimum frequency to start the motor with full load current and torque is the operating slip frequency.

The input phase voltage magnitude at start corresponds to the voltage resulting from the constant voltage/frequency ratio plus primary voltage drop with the starting frequency equal to the slip frequency. At frequencies near starting frequency the primary resistance voltage drop is large compared to the primary voltage magnitude and cannot be neglected. Simply holding the motor input volts per hertz constant will not produce sufficient output torque.

The starting current of a polyphase induction motor started across the line, at full voltage and frequency, is up to 700% of full load current with a power factor below 0.4. Starting an induction motor, at 100% starting torque, with an inverter offers a major advantage since the starting current is 100% of full load current with a power factor above 0.8.

Another mode of operation, constant horsepower, requires that a base speed be established. The base speed is the minimum speed at which the induction motor can be operated with a constant horsepower. This could be rated speed or some other speed. But since the required torque increases as the speed is decreased with constant horsepower operation the motor size is determined by the base speed.

For constant horsepower operation the frequency varies as the square of the input voltage above the base speed. The maximum available torque above base speed decreases inversely as the speed, which is the required torque for constant horsepower operation as illustrated in Figure 3. Operation below base speed must be with a constant volts per hertz to avoid magnetic saturation. Constant torque

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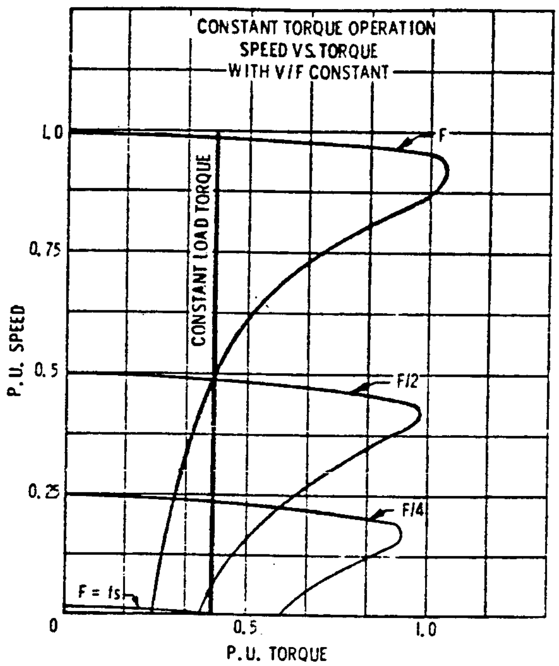

FIGURE 2. Speed vs. Torque with constant primary volts per hertz input power to the motor for constant torque operation.

Spray—Oil Cooled Motors

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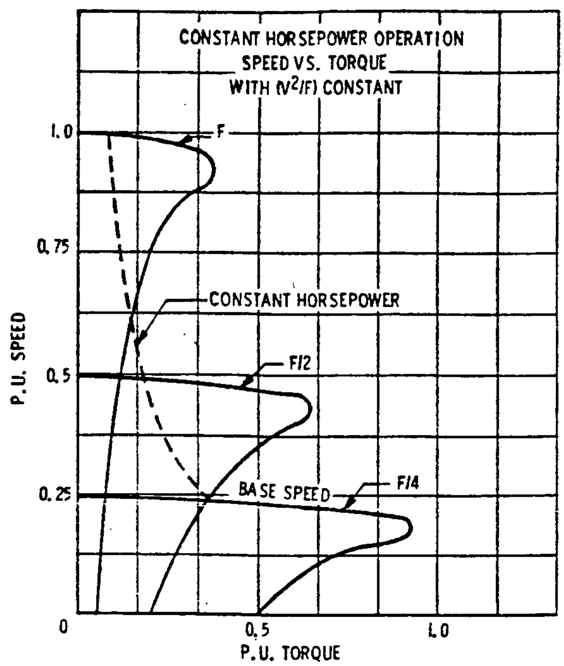


FIGURE 3. Speed vs. Torque with constant primary volts squared per hertz input power to the motor for constant horsepower operation

operation can be used in the speed range from start to base speed.

An induction motor operated at a reduced horsepower with full voltage magnitude and frequency pays a penalty in reduced performance. For operation with reduced loads, at optimum power factor and efficiency, the horsepower varies as the square of the voltage with constant frequency.

CONSTRUCTION A representative motor design is a two bearing assembly complete with a one-piece cast-frame, end bell, and shaft seal. A cross section of the oil-cooled motor design is illustrated in Figure 4. This motor design has provisions for both spray and conduction oil-cooling. Construction methods are the same as used on Westinghouse high speed oil-cooled generators.

The oil flow circuits, as illustrated in Figure 5, are suitable for turbine or engine oil. Cooling oil from the reservoir is pressurized and circulated by a positive displacement pump to the heat exchanger. Most of the cooled oil is routed through a sealed annual passage around the stator and returned to the reservoir. The balance is routed through a 20 to 50 micron (absolute) filter and into the anti-drive end of the motor to supply bearing lubrication and rotor cooling. Gravity drain or another positive displacement pump may be used to scavenge the rotor cooling oil from the motor cavity and return it to the reservoir.

For operation from 0 RPM to maximum speed, separate motor-driven supply and scavenge pumps are used. However, if the speed range is less than 2:1, integral direct drive pumps can be used. Depending on the application, the supply and scavenge pumps may be assembled in a one-piece housing and mounted on a common shaft or be separate pumps. The oil flow rate required for motor cooling is illustrated in Figure 6. The motor oil-cooling/lube system is also available to lubricate user equipment bearings, splines or gears for increased system reliability.

Cooling for the stator is primarily by conduction through the stack to a sealed annular passage around the stator. The pressurized cooling oil flows through this passage.

Cooling oil for the rotor enters the motor under pressure and flows through the passage on the anti-drive end and to the shaft through a transer tube. A small amount of oil is metered through a calibrated hole at each bearing to lubricate, cool, and flush the bearings and shaft seal. Cooling oil is sprayed from the nozzles at each end of the rotor stack onto the end rings. The nozzles are supplied a constant flow of oil at all operating speeds. After impinging on the end rings, the oil sprays radially onto the stator end turns to provide additional cooling to the stator windings. No oil flow is required or desired in the rotor-stator air gap.

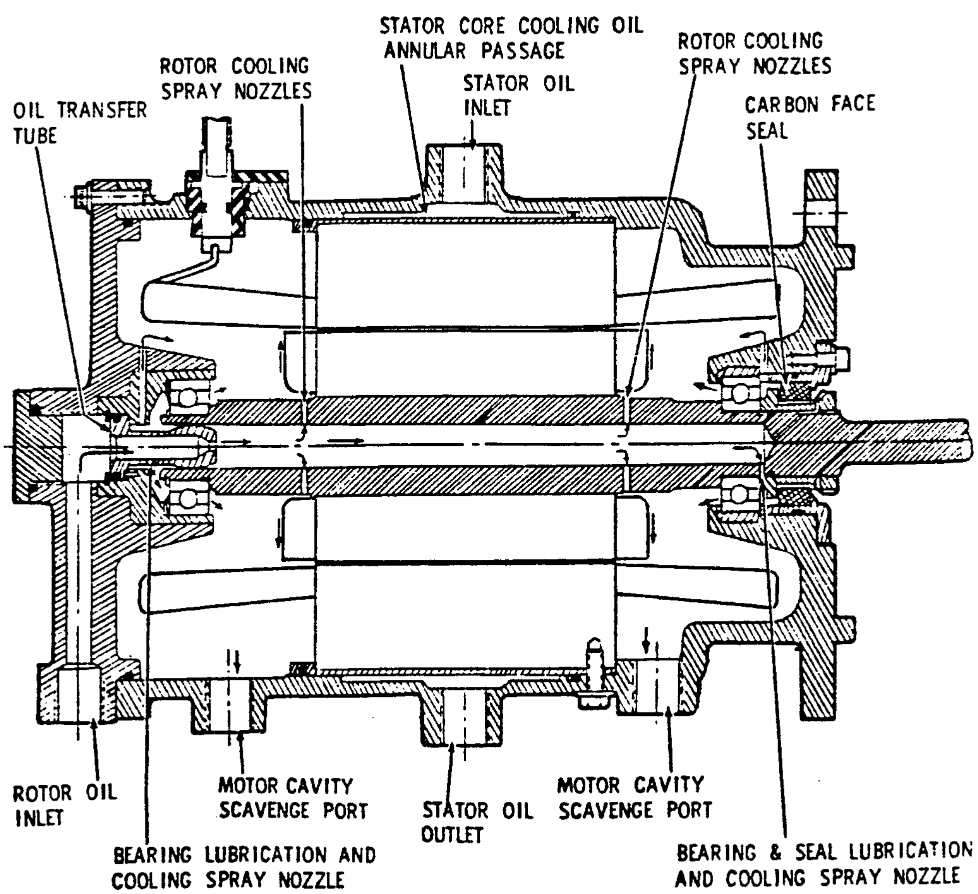


FIGURE 4. Typical spray oil-cooled motor cross section

Considerable kinetic energy (spray oil losses) is imparted to oil expelled from the end rings at high rotor speeds. Experiments have shown the spray oil losses are $MV^2 f(t)$, where M is the mass flow rate, V is the peripheral speed of the rotor, and f(t) is a weak function of the oil temperature. The spray oil losses would become excessive if the mass flow rate (M) of the oil was too high. Therefore the flow rate into the rotor is set by an orifice within the transfer tube, with the necessary addition of a pressure relief valve if integral pumps are driven over a variable speed range by the motor.

The technology for evacuation of a rotating machine has evolved from service experience with high speed spray oil-cooled generators. The motor cooling oil is scavenged from the motor cavity by a positive displacement scavenge pump or a gravity drain. For high speed operation the scavenge pump capacity is designed to exceed the solid oil flow rate into the rotor cavity. The scavenge becomes an emulsion of oil with a high level of gas. Thus, the pressure within the motor compartment is reduced with a proportional decrease in motor windage loss.

The insulations used in these motors have been selected to meet fabrication, processing, and service life requirements without using glass or other fibrous materials which could contaminate the oil supply. Round wire with heavy build DuPont ML enamel insulation, which meets NEMA MW 1000 16-C requirements, is used in all motor windings.

Electro-phoretic deposition of a polyamide-imide varnish by an exclusive Westinghouse process is used to insulate the steel laminated core. This involves electrolytic deposition of a 0.003 minimum single thickness of the insulation resin from an organic media. The deposited resin is then cured during a multi-step bake cycle. This process has the advantage of forming a uniform conformal coating on the core including good build up on small radius surfaces such as corners. The conformal coating in the stator bore and slot openings eliminates the possibility of damage to the magnet wire during winding. All sheet insulation is Kapton. The stator is ultrasonic impregnated with a polyamide-imide varnish. All insulations have very similar chemical structures, thus assuring proper bonding. This insulation system is impervious to oils, hydraulic fluids and most solvents.

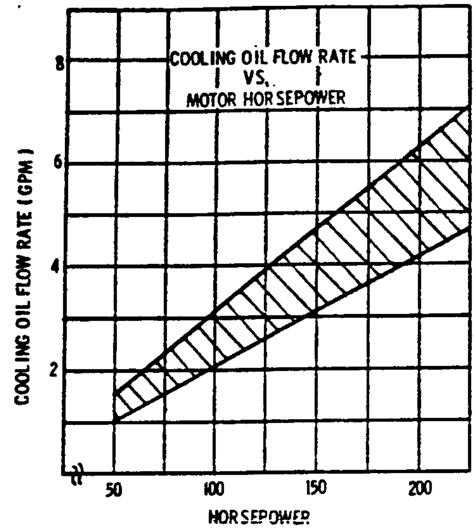


FIGURE 6. Cooling oil flow rate vs horsepower

The combination of high speed and spray oil results in high velocity oil leaving the rotor and impinging on the stator windings. Laboratory tests have shown that erosion from high velocity oil spray is influenced by shape and orientation of conductors relative to direction of spray and flow rate. Properly applied spray cooling does not induce erosion. Test results at comparable peripheral speeds demonstrate that these motor designs are capable of operation at speeds above 28,500 RPM with no erosion of the enamel on the round stator wire. These tests were also used to verify high speed windage and spray oil loss calculations.

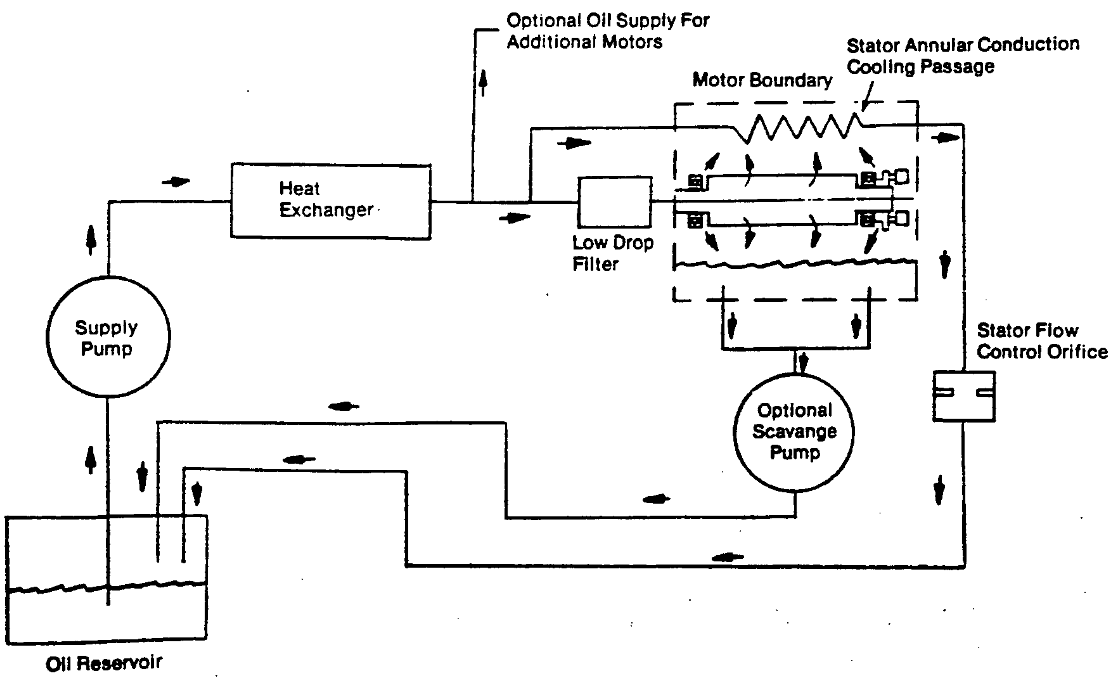


FIGURE 5. Typical oil flow circuit

Stator and rotor laminations are made from thin silicon electrical sheet steel for high frequency operation. A coating, to provide inter-laminar resistance, is used to reduce eddy currents, thereby reducing core loss.

Rotor conductor bars and end rings are made from dispersion strengthened copper. The conductor bars are electrically and Mechanically connected on each end of the laminated stack with an end ring to provide a very high strength rotor structure for high speed operation.

(continued on following page)

Spray Oil-Cooled Motors

(continued from following page)

MOTOR RATINGS Two motor designs can satisfy a complete range of 50 to 200 HP ratings at 24,000 RPM. Each motor is designed around the upper rating of the range without a sacrifice in efficiency at the low rating. One motor, rated from 50 to 125 HP, is 7.5 inches in diameter, 12 inches long and weighs 72 lbs. The other motor, rated from 125 to 200 HP, is 9 inches in diameter, 13 inches long and weighs 109 lbs.

As illustrated in Figure 7, the motor efficiency does not drop below 93 percent over the complete 50 to 200 HP range with a constant voltage, 3 phase, 400 Hz input power. Under the same operating conditions, the power factor drops to 86 percent at the low rating as illustrated in Figure 8. If the square of the terminal voltage per horsepower is held constant, with 400 Hz input frequency and decreased output power, the power factor will remain constant over the horsepower range, as illustrated in Figure 8. The speed will be 23,700 RPM at all power ratings and the efficiency will remain unchanged when operated with the reduced input voltage.

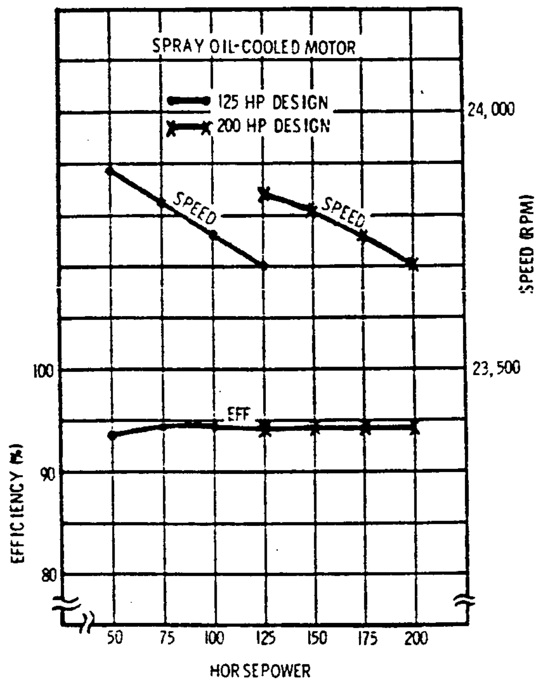


FIGURE 7. Efficiency and Speed vs HP Spray oil-cooled motor operated with constant voltage, 3 phase, 400 Hz input power from AC inverter drive

The 125 HP oil-cooled motor electromagnetic design is the same as a line of 40 to 70 HP, freon and helium gas-cooled compressor motors, operated with high frequency inverter drives at speeds up to 24,000 RPM. Some of these motors have been in service for over 10 years. The increased power rating is made possible by the improved heat transfer characteristics of spray oil-cooling.

SERVICE LIFE AND RELIABILITY Service life and reliability of the Westinghouse motors is high as a result of the low insulation operating temperatures. Figure 9 illustrates that with an inlet oil temperature of 60°C the motor winding hot spot temperature is less than 180°C at full load because of spray oil-cooling. The best voltage waveform for operation of a motor, a pure sine wave, was used for these calculations.

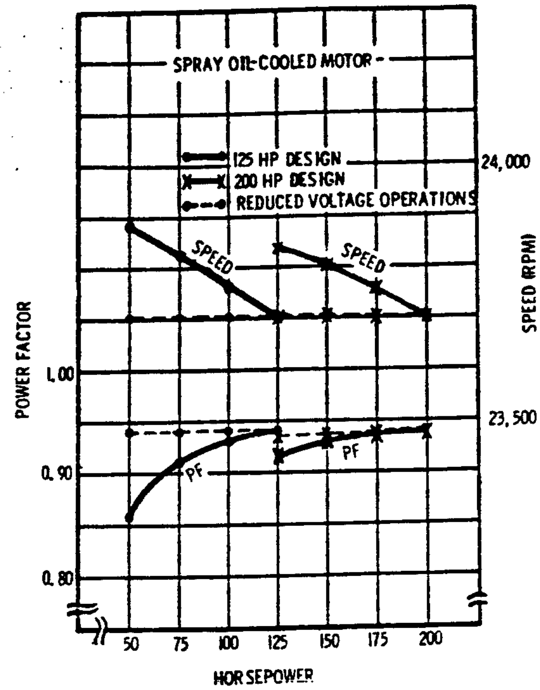


FIGURE 8. Power and Speed vs. Horsepower. Spray oil-cooled motor operated with constant voltage, 3 phase, 400 Hz input power from AC inverter drive. Dashed line illustrates correction of power factor by lowering input voltage.

An inverter supplied voltage is a switched waveform which is non-sinusoidal. The harmonic content, determined by Fourier analysis, varies widely depending on the type of inverter. Inverter designs which eliminate harmonics through the 17th are in production, while other designs have a 5th harmonic as high as 20% of the fundamental. Operation with the latter inverter would increase motor losses as much as 15%. Even with the added losses the hot spot temperature would be less than 200°C at full load with spray oil-cooling.

Use of the polyimide and polyamide-imide resin insulation materials results in the best state-of-the-art insulation

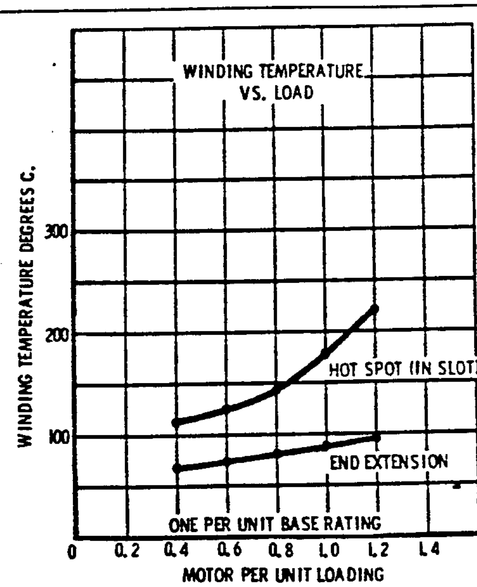
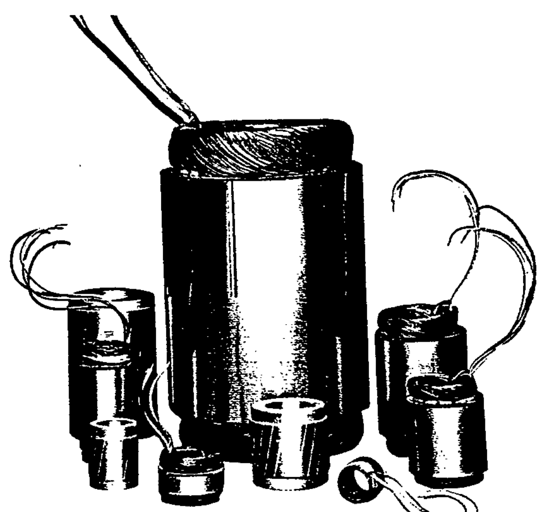


FIGURE 9. Motor winding temperatures are low because of spray oil-cooling. Winding temperatures are well within the tolerance of turbine oils, which presently is 230 to 240°C. The hot-spot temperature occurs on conductors buried in the slots midway of the stack length and therefore not directly exposed to oil. One per unit in this graph is 125 HP or 200 HP base rating of the motor at 23,700 RPM with 60°C oil inlet temperature.

Appendix G

Speed up to 200 000 rpm.

HF-Motorelements from KaVo EWL.



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HOFER

PRECISION TOOL IMPORTS Inc.

110 NEWPORT CENTER DR., SUITE 200E

NEWPORT BEACH, CA 92660

HIGH-FREQUENCY Motor-Elements – For what applications?

HF motor elements are used successfully as drives for grinding, milling and drilling, pumps, textile machinery, centrifuges. fans in physical, optical and medical equipment, also in the field of aerospace, in plastics and glass processing; i.e. in all fields of application where there is need for high speeds and favorable specific weight.

HIGH-FREQUENCY Motor-Elements – Why?

Because high and maximum speeds can be reached with great economic efficiency combined with freedom from maintenance and wear. HF motor elements have a long life time. The injection moulding of the rotors provides good balance and conditions and extreme smoothness of running. No additional measures are required for interference suppression of the HF motor elements. Having no carbon brushes the drive is spark free and therefore inherently safe for many applications. Further advantages are: no dirt accumulation caused by carbon dust, no low-speed drop under load, high power factor and efficiency through the use of especially low loss material. low operating cost through optimum adaptation to the relevant operating conditions.

HIGH-FREQUENCY Motor-Elements – Mode of operation

The HF motor element consists of the stator and rotor of a polyphase asynchronous motor. The speed of asynchronous motors is dependent on the number of poles of the motor and the supply frequency applied. It is independent of the motor voltage. The rotor speed is given by the equation:

$$n = \frac{f \times 120}{2\,p}$$

where f = Supply frequency in Hz
$2\,p$ = Number of poles of the motor
n = Rotor speed in rpm

The smallest number of poles which can be used is one pair ie $2\,p = 2$. When connected to a 50 Hz mains supply, this will give a maximum speed of 3000 rpm . An increase in speed beyond this is only possible by applying a higher supply frequency. To do this, the mains frequency of 50 Hz must be converted to the frequency required by means of a frequency converter. This frequency is calculated according to the speed requirement from the equation:

$$f = \frac{2\,p \times n}{120}$$

where f = Supply frequency in Hz
$2\,p$ = Number of poles of the motor
n = Rotor speed in rpm

HIGH-FREQUENCY Motor-Elements – Power outputs

The power output which can be achieved is basically determined by the design size and the supply frequency of the HF motor element.

Continuous power –

The magnitude of the power output is dependent on the type of cooling (water, oil, air, no cooling) and its efficiency as well as on the temperatures pertaining in individual cases.

Peak power –

is the maximum power which the motor can achieve for short periods under normal conditions. Also important here is the type and quality of cooling. In this respect, please pay particular attention to the remarks regarding the power rating.

HIGH-FREQUENCY drive systems from one source

Our HF motor elements and HF frequency converters provide a perfect match in conformity with requirements. A list of the HF frequency converter series is given on the back page.

HIGH-FREQUENCY Motor-Elements – Design

Stators

are available with single-phase or polyphase windings. Slot insulation and winding impregnation comply with class F of VDE Regulation 0530. Maximum permissible sustained temperature is 155° C. The flexible leads are generally designed with Teflon insulation and they are oil resistant. For temperature monitoring, thermal switches (PTC resistors) can be fitted. Dimensions are specified in the standard program. Windings are supplied in accordance with customer specifications. The stators have to pass a 100 % test with impulse voltage. Caution. Do not use PWM-Converter without filter where voltage increase > 400 V/ µsec.

Rotors

The cage consists of specially selected high-pressure die-cast material. This ensures 100 % filling of the slot cavity, so that great mechanical strength of the rotor is achieved and the out of balance centrifugal forces are low. This inherent balance remains constant. The speed quoted in the specification is the upper limit. Special modifications can be made to reach higher speed, for example armouring or closed groove.

HIGH-FREQUENCY Motor-Elements – Special design

Special types will by supplied on request with a different number of poles, alternative power ratings and non-standard physical dimensions. Design as a synchronized asynchronous motor (reluctance motor) is possible.

KaVo EWL has great experience in the design and manufacture of high-speed motor drives. HF motor elements are supplied worldwide to special drive system OEMs. To provide optimum solutions to problems, a well-equipped research laboratory is available for development and trials.

Every HF motor element is specially tailored to requirements in respect of speed, frequency, power and size. The questionnaire enclosed can be used to determine the most suitable HF motor element.

Standard range - 2pole, 4pole, 6pole

The values in this table are peak power and continuous power under normal magnetic utilization and based on given frequency steps. The number of poles is indicated by the last digit in the type designation.

TYPE Ø– Length. poles	Power in kW									
	f = 250 Hz = 15000/min		f = 500 Hz = 30000/min		f = 1000 Hz = 60000/min		f = 1500 Hz = 90000/min		f = 2000Hz = 120000/min	
	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$
EV 30 - 10.2			0,014	0,014	0,05	0,04	0,095	0,07	0,14	0,09
- 20.2			0,045	0,045	0,15	0,11	0,27	0,17	0,38	0,21
- 30.2			0,081	0,076	0,26	0,17	0,45	0,26	0,64	0,32
- 40.2			0,12	0,106	0,37	0,23	0,64	0,34	0,9	0,44
EV 40 - 10.2			0,04	0,039	0,13	0,11	0,21	0,18	0,3	0,23
- 20.2			0,12	0,011	0,34	0,28	0,55	0,42	0,75	0,54
- 30.2			0,22	0,19	0,58	0,43	0,92	0,63	1,23	0,81
- 40.2			0,33	0,28	0,85	0,62	1,34	0,91	1,77	1,17
- 50.2			0,44	0,37	1,12	0,79	1,75	1,17	2,29	1,50
- 60.2			0,55	0,45	1,38	0,95	2,13	1,39	2,79	1,79
EV 48 - 15.2	0,05	0,05	0,16	0,15	0,43	0,36	0,68	0,54	0,92	0,7
- 20.2	0,08	0,07	0,24	0,23	0,62	0,50	0,98	0,75	1,3	0,97
- 25.2	0,11	0,10	0,34	0,30	0,85	0,66	1,32	0,97	1,74	1,25
- 30.2	0,15	0,14	0,44	0,38	1,08	0,81	1,66	1,19	2,19	1,52
- 40.2	0,22	0,21	0,64	0,53	1,54	1,09	2,35	1,6	3,1	2,04
- 50.2	0,3	0,29	0,86	0,68	2,0	1,4	3,0	2,0	4,0	2,6
- 60.2	0,39	0,36	1,08	0,83	2,5	1,7	3,8	2,4	4,9	3,15
EV 54 - 15.2	0,06	0,06	0,22	0,20	0,63	0,48	1,0	0,72	1,4	0,93
- 30.2	0,21	0,20	0,71	0,54	1,89	1,13	3,0	1,65	4,0	2,12
- 45.2	0,4	0,36	1,28	0,85	3,3	1,75	5,1	2,54	6,8	3,26
- 60.2	0,6	0,50	1,9	1,16	4,8	2,36	7,5	3,43	9,5	4,38
EV 60 - 20.2	0,2	0,2	0,62	0,54	1,5	1,15	2,3	1,70		
- 30.2	0,39	0,37	1,1	0,87	2,7	1,81	4,2	2,65		
- 45.2	0,71	0,61	2,0	1,37	4,7	2,80	7,2	4,08		
- 60.2	1,0	0,85	2,9	1,88	6,8	3,78	10,0	5,5		
- 80.2	1,5	1,17	4,2	2,55	9,6	5,10	14,5	7,41		

TYPE Ø–Length. pole	f = 100 Hz = 6000/min		f = 250 Hz = 15000/min		f = 500 Hz = 30000/min		f = 750 Hz = 45000/min		f = 1000 Hz = 60000/min	
	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$
EV 70 - 20.2	0,055	0,055	0,3	0,30	0,9	0,78	1,6	1,2	2,27	1,65
- 50.2	0,23	0,22	1,2	0,99	3,35	2,19	5,6	3,3	7,8	4,41
- 70.2	0,38	0,37	1,9	1,45	5,2	3,15	8,6	4,7	12,0	6,28
- 100.2	0,61	0,60	3,0	2,15	8,2	4,59	13,5	6,85	18,6	9,10
EV 83 - 15.2	0,07	0,07	0,37	0,37	1,03	0,92	1,72	1,44	2,4	1,93
- 30.2	0,26	0,25	1,25	1,04	3,25	2,26	5,35	3,43	7,35	4,50
- 40.2	0,4	0,39	1,84	1,47	4,7	3,15	7,5	4,75	10,0	6,25
- 55.2	0,63	0,62	2,83	2,04	7,1	4,3	11,3	6,47	15,3	8,5
- 70.2	0,82	0,79	3,55	3,31	8,7	5,39	13,7	6,18	18,6	10,6
- 90.2	1,15	1,07	4,9	4,22	11,8	6,94	18,5	10,38	25,0	13,6
- 100.2	1,3	1,20	5,5	3,7	13,0	7,7	20,5	11,49	27,5	15,0
EV 90 - 40.2	0,55	0,52	2,3	1,7	5,7	3,7	9,7	5,6	12,4	7,2
- 60.2	0,90	0,81	4,3	2,8	9,8	5,6	15,5	8,4	23,2	11,3
- 80.2	1,4	1,21	6,0	3,8	14,8	7,8	25,0	11,6	31,6	15,1
- 100.2	2,0	1,61	8,0	4,7	21,0	10,0	33,0	14,0	41,6	19,0
EV 106 - 50.2	1,5	1,3	6,4	4,1	14,0	8,4	23,3	12,6		
- 80.2	2,8	2,3	11,7	6,9	28,2	14,4	37,3	19,8		
- 100.2	3,7	2,9	16,3	8,9	39,0	18,2	49,0	25,0		
- 130.2	5,0	3,9	22,3	11,5	50,0	23,1	72,6	34,0		
- 150.2	6,1	4,5	25,4	13,1	51,5	25,4	94,2	39,5		
EV 120 - 50.2	1,7	1,6	6,6	5,1	15,5	10,5	23,9	15,7		
- 60.2	2,0	1,9	7,7	5,7	18,0	11,7	28,0	17,5		
- 80.2	3,0	2,6	11,5	7,8	26,6	16,0	41,2	23,7		
- 90.2	3,6	3,0	13,5	8,8	31,0	18,0	48,0	27,0		
- 120.2	5,2	4,2	19,5	12,0	44,6	24,4	68,4	36,2		
EV 135 - 50.2	2,8	2,5	8,1	7,3	17,6	15,2				
- 80.2	5,0	4,5	15,6	12,6	33,6	25,7				
- 100.2	6,9	6,0	22,0	16,4	42,0	32,0				
- 125.2	9,0	7,5	26,4	20,0	56,0	40,5				
- 160.2	12,2	10,0	40,0	26,1	84,0	52,6				
EV 140 - 50.2	2,7	2,6	10,0	8,2	20,3	16,8				
- 80.2	6,1	5,2	20,0	14,9	38,0	28,0				
- 100.2	8,2	6,8	25,0	18,1	61,0	37,0				
- 125.2	11,0	8,6	34,0	22,4	65,0	42,5				
- 180.2	16,5	12,1	55,0	33,9	120,0	68,0				

TYPE Ø– Length. poles	Power in kW f = 200 Hz = 6000/min		f = 500 Hz = 15000/min		f = 1000 Hz = 30000/min		f = 1500 Hz = 45000/min		f = 2000Hz = 60000/min	
	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$
EV 65 - 30.4	0,17	0,17	0,67	0,57	1,5	1,15	2,35	1,63	2,95	2,08
- 45.4	0,29	0,28	1,1	0,88	2,45	1,76	3,7	2,5	4,7	3,18
- 60.4	0,42	0,40	1,55	1,20	3,4	2,38	5,1	3,5	6,5	4,27
EV 80 - 30.4	0,41	0,40	1,5	1,20	3,3	2.42	4.9	3.5	6,4	4.42
- 45.4	0,71	0,65	2,5	1,86	5,4	3,69	8,0	5,25	10,3	6.66
- 60.4	1,0	0,91	3,5	2,54	7,5	4,99	11,0	7,15	14,0	8,98
- 75.4	1,35	1,16	4,5	3,21	9,6	6,28	14,0	8,95	18,0	11,37
- 90.4	1,65	1.42	5,5	3,87	11,5	7,57	17,0	10,80	22.0	13,6
EV 90 - 45.4	1,3	1,1	4,3	2,9	9,4	5,7	13,1	8,0		
- 60.4	1,8	1,4	6,0	4,0	12,8	7.6	18.3	10.6		
- 75.4	2,4	1,8	8,4	5,0	18,0	9,8	24,0	13,8		
- 90.4	2,8	2,1	9,8	5,9	21,0	11.5	29,0	16,1		
EV 106 - 50.4	2,5	2,0	7,5	5,4	13,7	10,1	18,8	14,3		
- 80.4	4,2	3,4	12,4	8,8	22,8	16.3	33,3	23,3		
- 100.4	6,0	4,4	19,2	11,4	29,9	20.9	40,8	29,3		
- 130.4	7,1	5,5	21,8	14,7	37,5	27,2	54,0	37,8		
- 150.4	9,1	6,7	29,0	17,5	43,6	31.0	63,0	43,4		
EV 120 - 50.4	3,1	2,9	9,1	7,5	18,6	15,4				
- 90.4	7,8	5,9	18,4	14,6	37,2	28,7				
- 120.4	11,5	8.2	26,0	19,7	51,4	38,5				
- 150.4	11,4	9,5	32,6	23,8	65,6	46.5				
EV 135 - 50.4	7,6	4,8	18,0	12,5	40,0	24,0				
- 80.4	11,7	7,9	33,0	20,1	65,6	38,2				
- 100.4	16,5	10,0	45,5	25,0	81,0	47,2				
- 130.4	19,8	12,9	54,7	32,9	108,0	62,0				
- 160.4	26,1	16,3	72,0	40,9	143,0	78,0				
- 230.4	34,5	22.3	83,4	55,0	169,0	103.0				
EV 140 - 50.4	5,7	4.8	16,1	12,4	30,4	24,3				
- 100.4	13,3	10,1	34,0	25,6	68,0	50,1				
- 160.4	22,3	16,8	56,8	40,0	114,0	79,3				
- 240.4	34,6	25,5	80,6	60,2	160,0	118,0				
EV 150 - 50.4	8,2	6,1	19,9	15,1						
- 100.4	21,4	15,0	50,0	32,0						
- 150.4	36,0	20,0	84,0	48,2						
- 220.4	46,0	30.0	120,0	72,0						
EV 165 - 50.4	12,8	7,9	32,0	20,0						
- 100.4	30,0	20,0	78,0	44,0						
- 150.4	52,0	30,0	148,0 .	64,0						
- 200.4	66,0	40,0	168,0	85,0						

TYPE Ø– Length. poles	f = 300 Hz = 6000/min		f = 750 Hz = 15000/min		f = 1500 Hz = 30000/min		f = 2250 Hz = 45000/min		f = 3000 Hz = 60000/min	
	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$	$V_R + P_{max}$	$V_R + P_2$
EV 80 - 30.6	0,52	0,42	1,8	1,1	3,6	2,0	5,2	2,9	6,4	3,2
- 90.6	2,s0	1,4	6,0	3,5	12,3	6,1	17,5	8,8	18,7	10,0
EV 90 - 30.6	0,65	0,57	2,2	1,55	4,6	2,9	6,6	4,0		
- 60.6	1,6	1,3	5,0	3,4	10,2	5,4	14,5	8,8		
- 90.6	2,5	1,9	7,8	4,8	15,5	9,1	22,3	12,6		
EV 106 - 50.6	2,4	1,9	6,9	4,9	13,7	9,3				
- 100.6	5,2	3,9	14,7	9,8	28,8	18,3				

Remarks concerning performance data

1) The before mentioned power outputs is: $V_R + P_{max}$ = peak power and $V_R + P_2$ = continuous power with water cooling.
2) The listed power outputs do not take into account the losses (type of bearing, windage etc.) produced by rotation (VR). In order to calculate the maximum power obtainable at the shaft, these losses must be deducted.
3) The power outputs stated are approximate values and apply to the stated frequencies with a linear voltage/frequency ratio over the range of stated frequencies with sinusoidal current.
   In certain circumstances, changes in power output is possible with voltages/frequency ratios other than those quoted. Higher power outputs may sometimes be obtained, particularly in the case of lower frequencies through appropriate matching of the voltage/frequency ratio.
   An increase in power output may also be possible in certain circumstances when operating with only one frequeny or a relatively narrow frequency range.
4) Deviations from the power outputs stated may occur due to the following factors:
   – voltage stability/power rating and quality of the frequency converter
   – structural design of the drive (e.g. additional losses, leakages, length of commutator ring version etc.)
   – choice of shaft material and/or bore diameter. (The power outputs stated assume the use of a magnetically conductive shaft of solid material, whose size conforms to the normal value $d_3$nom. given in the table. If, for example, the mechanical design requires larger shafts or hollow shafts, then a reduction in power output can be expected, as is also the case when using non-magnetic shaft material).
   – in the case of high frequencies and/or low voltages, there may be wide power fluctations in certain circumstances due to the type of winding needed.
   – According to the operating temperature the power output may slightly differ.
5) With drives used only at relatively low speeds, the power output may in certain circumstances be increased by using different materials.

Appendix H

POWER OUTPUT—BHP

Engine Speed r/min	Continuous Power (Fixed Speed)			Intermittent Power (Fixed Speed)			Automotive Power		
	BS5514/ISO 3046/DIN 6271						DIN 70020		
	LPW2	LPW3	LPW4	LPW2	LPW3	LPW4	LPW2	LPW3	LPW4
3600	18.8	28.2	37.5	20.6	31.0	41.3			
3000	18.0	26.9	35.9	19.7	29.6	39.5	20.1	30.3	40.3
2500	15.3	22.9	30.6	16.8	25.2	33.6	17.8	26.7	35.7
2000	12.3	18.5	24.7	13.5	20.4	27.1	14.5	21.6	29.0
1800	11.0	16.5	22.0	12.1	18.1	24.1	12.7	19.3	25.6
1500	8.8	13.3	17.7	9.8	14.6	19.4	9.9	15.0	19.8

TORQUE

Engine Speed r/min		Continuous Power (Fixed Speed)			Intermittent Power (Fixed Speed)			Automotive Power		
		BS5514/ISO 3046/DIN 6271						DIN 70020		
		LPW2	LPW3	LPW4	LPW2	LPW3	LPW4	LPW2	LPW3	LPW4
3600	Nm (lbf ft)	37.1 (27.4)	55.7 (41.4)	74.3 (54.8)	40.8 (30.1)	61.3 (45.2)	81.7 (60.3)			
3000	Nm (lbf ft)	42.7 (31.5)	64.0 (47.2)	85.3 (62.9)	46.9 (34.6)	70.4 (51.9)	93.8 (69.2)	47.8 (35.3)	71.9 (53.0)	95.9 (70.7)
2500	Nm (lbf ft)	43.5 (32.1)	65.3 (48.2)	87.0 (64.2)	47.9 (35.3)	71.8 (53.0)	95.8 (70.7)	50.7 (37.4)	76.1 (56.1)	101.5 (74.9)
2000	Nm (lbf ft)	43.9 (32.4)	65.9 (48.6)	87.8 (64.8)	48.3 (35.6)	72.5 (53.5)	96.6 (71.2)	51.7 (38.1)	77.1 (56.9)	102.9 (75.9)
1800	Nm (lbf ft)	43.5 (32.1)	65.3 (48.2)	87.0 (64 2)	47.9 (35.3)	71.8 (53.0)	95.7 (70.6)	50.9 (37.5)	76.4 (56.3)	101.4 (74.8)
1500	Nm (lbf ft)	42.0 (31.0)	63.0 (46.5)	84.0 (62.0)	46.2 (34.1)	69.3 (51.1)	92.4 (68.2)	49.0 (36.1)	73.2 (54.0)	94.3 (69.6)

Rating: BS5514/ISO 3046/DIN 6271
Note that 10% overload ratings apply only to a fully run-in engine.

Derating: BS5514/ISO 3046/DIN 6271
Altitude: Approx. 3½% for every 1000ft (300m) above 500ft (150m) above sea level.
Air inlet temperature: Approx. 2% for every 10°F (5½°C) above 85°F (30°C).
Humidity: Up to a maximum of 6%.

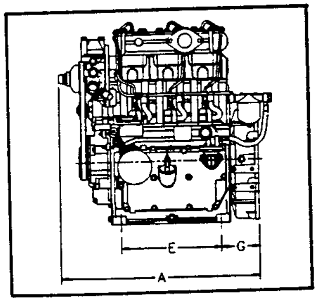
TECHNICAL DATA

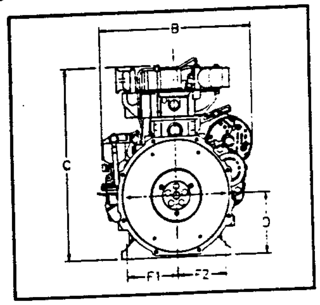
		LPW2	LPW3	LPW4
Bore:	ins: (mm):	3.38 (86.0)	3.38 (86.0)	3.38 (86.0)
Stroke:	ins: (mm):	3.15 (80.0)	3.15 (80.0)	3.15 (80.0)
Cylinder Capacity:	ins³: (l):	56.7 (0.930)	85.1 (1.395)	113.5 (1.860)
Lubricating Oil Capacity: (including Filter)	US quarts: (liters):	3.4 (3.2)	4.7 (4.4)	5.8 (5.5)
Lubricating Oil Consumption:		Less than .75% of full load fuel consumption		
Fuel Consumption: 100% load @ 2500r/min. (Subject to 5% tolerance)	U.S. gal/h: (l/h):	0.84 (3.2)	1.25 (4.7)	1.67 (6.3)
Angles of Inclination:	Permanent: Temporary:	20° 25°	20° 30°	20° 30°
Minimum Idling Speed:	r/min:	850	850	850
Combustion Air Required at 2000r/min:	ft³/m: (l/s):	27.90 (13.17)	41.85 (19.75)	55.80 (26.33)
Dry Weight (including Flywheel):	lbs: (kg):	247 (112)	330 (150)	396 (180)
ELECTRICAL SYSTEM				
Alternator Output:	amps:	45	45	45
Starter Motor Power:	kW:	1.6	1.6	2.0
Starter Motor Battery Cold Cranking Performance Rating: (BS3911-Part 2)	amps 18°F/-8°C:	285	345	380
	amps 0°F/-18°C:	515	600	670
***Minimum Starting Temperature** (without additional aids)	°F: (°C):	5° (-15°)	5° (-15°)	5° (-15°)

*Consult Lister-Petter concerning performance at lower temperatures.

Information is intended for the assistance of users and is based upon results obtained from tests performed at the place of manufacture. This company does not guarantee that the same results will be obtained elsewhere under different conditions and in certain applications. The information in this brochure does not form part of any contract, guarantee or warranty. We have made efforts to insure that the information is accurate, but reserve the right to amend specifications and information without notice and without obligation or liability.

PRINCIPAL DIMENSIONS





Inches (mm)	LPW2	LPW3	LPW4
A	18.2 (462.3)	22.1 (561.3)	26.1 (622.9)
B	17.3 (439.4)	17.3 (439.4)	17.3 (439.4)
C	21.0 (533.4)	21.0 (533.4)	21.0 (533.4)
D	6.7 (170.2)	6.7 (170.2)	6.7 (170.2)
E	7.2 (182.9)	11.2 (284.5)	15.1 (383.5)
F1	5.8 (147.3)	5.8 (147.3)	5.8 (147.3)
F2	5.6 (142.2)	5.6 (142.2)	5.6 (142.2)
G	4.3 (109.2)	4.3 (109.2)	4.3 (109.2)

STANDARD EQUIPMENT

- Automatic excess fuel device
- Dipstick
- Engine speed setting
- Flywheel drilled for automotive clutch
- Flywheel housing with SAE5 flange
- Fuel filter
- Fuel lift pump
- Gray paint finish
- Hydraulic valve lifters
- Inlet & exhaust manifolds
- Inlet manifold heater plug & relay
- Lifting eye
- Lubricating oil filter
- Mechanical governor — fixed or variable speed
- Operator's handbook
- Radiator with cooling fan — mounted
- Sealed crankcase breathing system
- Self-vent fuel system
- Stop/run control device
- Tapping for speed detection probe
- Water circulation pump and thermostat
- 12 volt starter motor

PRODUCT SUPPORT

- Master parts manual
- Recommended spares kits
- Special service tools
- Workshop manual

ACCESSORIES

- Air cleaners — medium or heavy duty
- Alternative speed and stop/run control devices
- Engine protection switches and solenoids
- Exhaust flanges or mufflers
- Fan drive guards
- Flywheel end drives, shaft extensions, couplings, SAE industrial clutches
- Gauges — supplied loose
- Gear end drives
- Hydraulic pump drives — gear end and/or flywheel end
- Radiators — mounted or loose, with or without cooling fans
- Start panels — mounted or loose
- 45 amp battery charging alternator
- 3.2 US gallon (12 liter) fuel tank, fuel agglomerator

Lister-Petter Inc. • 815 East 56 Highway • Olathe, Kansas 66061 • USA • Telephone 913/764-3512 • Fax 913/764-5493
Manufacturers of industrial diesel and natural gas engines, generating sets and marine engines.

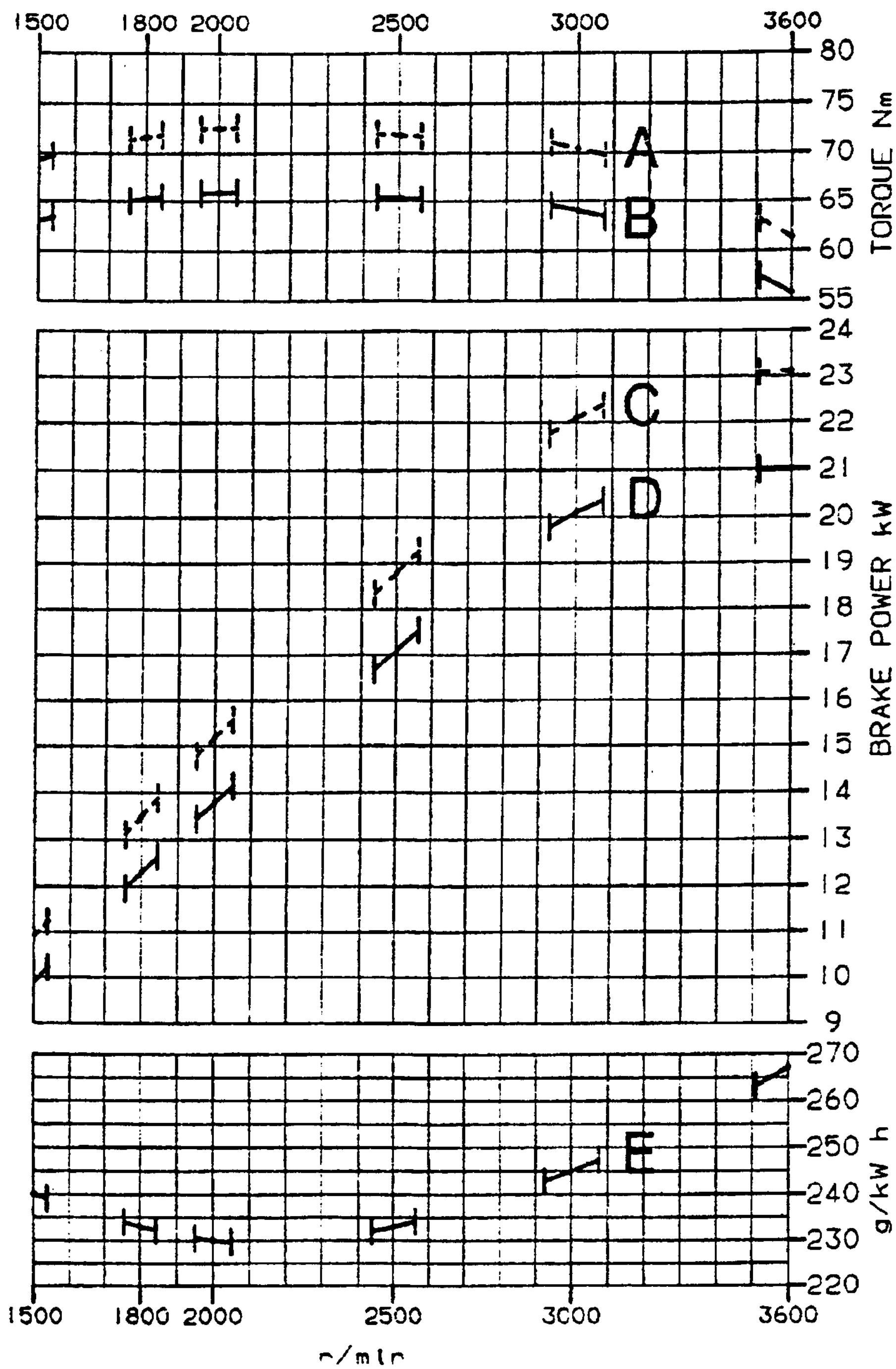
555-00263LPW

LPA, LPW and LPWS
Technical Sales Information

027-08247

Section Two - LPW and LPWS

LPW3 Fixed Speed Performance



A - Overload Torque
B - Continuous Torque
C - Overload Power
D - Continuous Power
E - Full Load Fuel Consumption

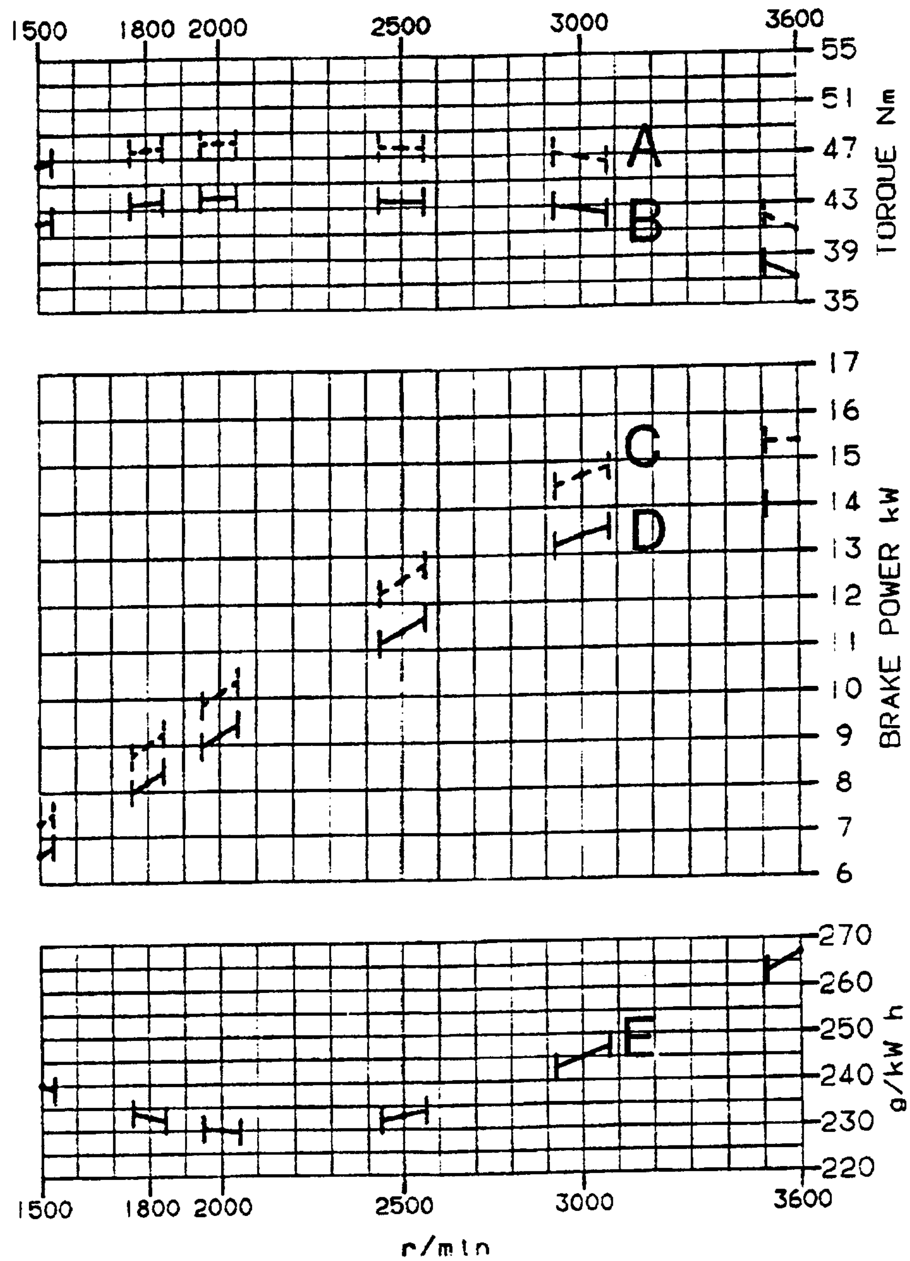
The above ratings are in accordance with BS5514, ISO3046 and DIN6271.
Rating Definitions are given in "Section Four".

Section Two - LPW and LPWS

Post-it® Fax Note 7671

Date 5/31/95	# of pages ▸ 2
To Peter Shapiro	From Mark Binns
Co./Dept. JSP Ind.	Co. Lister-Petter
Phone #	Phone #
Fax # 381-6189	Fax # 764-1613

LPW2 Fixed Speed Performance



A - Overload Torque
B - Continuous Torque
C - Overload Power
D - Continuous Power
E - Full Load Fuel Consumption

The above ratings are in accordance with BS5514, ISO3046 and DIN6271.
Rating Definitions are given in "Section Four".

Builds

Build	Details
01	Variable speed to 3000r/min - no overload
02	Variable speed to 3000r/min with overload
03	Variable speed to 3000r/min smoke limited
04	Variable speed to 3000r/min smoke limited
05	Variable speed to 3000r/min with overload
07	Fixed speed 1500r/min
08	Fixed speed 1800r/min
09	Fixed speed 3000r/min
10	Fixed speed 3600r/min
11	Automotive, variable speed to 2800r/min
40	Variable speed to 3000r/min - no overload
41	Fixed speed 1500r/min
42	Variable speed to 3000r/min with overload
43	Fixed speed 1800r/min
44	Fixed speed 3000r/min
45	Variable speed to 2500r/min - no overload
70	Variable speed to 3000r/min - no overload
71	Fixed speed 2000r/min
72	Fixed speed 1800r/min
73	Variable speed to 2500r/min with overload
75	Variable speed to 3000r/min with overload
76	Automotive, variable speed to 2800r/min

Notes:

Some Builds may not be available in all engines or cylinder configurations.

Where the build number is preceded by a 9 this indicates that the engine is either of a non-standard configuration, or contains non-standard parts or accessories.

When new parts are required for such a build it is suggested that reference be made to the manufacturer to determine the exact engine specification and which parts are non-standard.

Oil Consumption

Maximum in 24 hours at full load

	r/min	1500	1800	2000	2500	3000
LPW2	l	0.34	0.41	0.45	0.57	0.70
	pt	0.60	0.72	0.80	1.00	1.24
	US qt	0.36	0.43	0.48	0.49	0.74
LPW3	l	0.51	0.61	0.68	0.85	1.06
	pt	0.90	1.08	1.20	1.50	1.86
	US qt	0.54	0.65	0.72	0.90	1.12
LPW4	l	0.68	0.82	0.91	1.14	1.41
	pt	1.20	1.44	1.60	2.01	2.48
	US qt	0.72	0.87	0.96	1.20	1.49
LPWS2	l	0.38	0.45	0.53	0.64	0.79
	pt	0.66	0.80	0.92	1.12	1.39
	US qt	0.40	0.48	0.55	0.67	0.83
LPWS3	l	0.55	0.67	0.79	0.96	1.19
	pt	0.97	1.18	1.39	1.69	2.09
	US qt	0.58	0.71	0.83	1.01	1.25
LPWS4	l	0.74	0.90	1.05	1.28	1.58
	pt	1.30	1.58	1.85	2.25	2.78
	US qt	0.78	0.95	1.11	1.35	1.67

BMEP - Continuous Power, Fixed Speed

r/min	1500	1800	2000	2500	3000
bar	5.68	5.88	5.94	5.88	5.77
lbf/in²	82.38	85.28	86.15	85.28	83.68

Fuel Consumption

Specific fuel consumption, subject to 5% tolerance, is given within the power curve section.
In the following tables the 100% load figures are subject to 5% tolerance but all others are approximate and not guaranteed

100% Load

	r/min	1500	1800	2000	2500	3000
LPW2	l/h	1.9	2.3	2.5	3.2	3.9
	pt/h	3.3	4.0	4.4	5.6	6.9
	US gal/h	0.50	0.60	0.67	0.84	1.03
LPW3	l/h	2.8	3.4	3.8	4.7	5.9
	pt/h	5.0	6.0	6.7	8.4	10.3
	US gal/h	0.75	0.90	1.00	1.25	1.55
LPW4	l/h	3.8	4.6	5.0	6.3	7.8
	pt/h	6.6	8.0	8.9	11.1	13.8
	US gal/h	1.00	1.20	1.33	1.67	2.07
LPWS2	l/h	2.1	2.5	2.9	3.5	4.4
	pt/h	3.7	4.4	5.1	6.2	7.7
	US gal/h	0.55	0.67	0.77	0.93	1.10
LPWS3	l/h	3.1	3.7	4.4	5.3	6.6
	pt/h	5.4	6.6	7.7	9.4	11.6
	US gal/h	0.81	0.99	1.16	1.41	1.74
LPWS4	l/h	4.1	5.0	5.8	7.1	8.8
	pt/h	7.2	8.8	10.3	12.5	15.5
	US gal/h	1.08	1.32	1.54	1.87	2.32

75% Load

	r/min	1500	1800	2000	2500	3000
LPW2	l/h	1.5	1.8	2.0	2.5	3.1
	pt/h	2.6	3.1	3.5	4.3	5.4
	US gal/h	0.39	0.47	0.53	0.66	0.82
LPW3	l/h	2.2	2.7	3.0	3.7	4.6
	pt/h	3.9	4.7	5.2	6.5	8.1
	US gal/h	0.59	0.71	0.79	0.99	1.22
LPW4	l/h	2.9	3.6	3.9	4.9	6.1
	pt/h	5.2	6.3	6.9	8.7	10.7
	US gal/h	0.79	0.95	1.05	1.32	1.63
LPWS2	l/h	1.6	2.0	2.3	2.8	3.4
	pt/h	2.9	3.5	4.0	4.8	6.0
	US gal/h	0.43	0.53	0.61	0.74	0.92
LPWS3	l/h	2.4	2.9	3.4	4.2	5.1
	pt/h	4.2	5.1	6.0	7.3	9.0
	US gal/h	0.64	0.78	0.91	1.11	1.37
LPWS4	l/h	3.2	3.9	4.6	5.5	6.9
	pt/h	5.6	6.8	8.0	9.7	12.1
	US gal/h	0.85	1.04	1.22	1.48	1.83

50% Load

	r/min	1500	1800	2000	2500	3000
LPW2	l/h	1.1	1.3	1.6	1.8	2.3
	pt/h	1.9	2.3	2.6	3.2	4.0
	US gal/h	0.29	0.35	0.39	0.49	0.61
LPW3	l/h	1.6	2.0	2.2	2.8	3.4
	pt/h	2.9	3.5	3.9	4.8	6.0
	US gal/h	0.44	0.53	0.59	0.74	0.91
LPW4	l/h	2.2	2.6	2.9	3.7	4.5
	pt/h	3.9	4.6	5.1	6.5	8.0
	US gal/h	0.59	0.71	0.78	0.98	1.21
LPWS2	l/h	1.2	1.5	1.7	2.0	2.5
	pt/h	2.1	2.6	3.0	3.6	4.5
	US gal/h	0.32	0.39	0.45	0.55	0.68
LPWS3	l/h	1.8	2.2	2.5	3.1	3.8
	pt/h	3.1	3.8	4.5	5.4	6.7
	US gal/h	0.48	0.58	0.68	0.83	1.02
LPWS4	l/h	2.4	2.9	3.4	4.1	5.1
	pt/h	4.2	5.1	6.0	7.2	9.0
	US gal/h	0.63	0.77	0.90	1.10	1.36

Air Flows and Pressures

Combustion Air Consumption

	r/min	1500	1800	2000	2500	3000
LPW/S2	l/sec	9.87	11.85	13.17	16.46	19.75
	ft^3/min	20.92	25.11	27.90	34.87	41.85
LPW/S3	l/sec	14.81	17.77	19.75	24.69	29.62
	ft^3/min	31.39	37.66	41.85	52.31	62.77
LPW/S4	l/sec	19.75	23.70	26.33	32.92	39.50
	ft^3/min	41.85	50.22	55.80	69.75	83.70

SECTION FIVE - FORMULAE AND CONVERSIONS

Formulae

BMEP

$$\text{Bar} = \frac{\text{kW} \times 60000 \times 20000}{\text{Cylinders} \times \text{r/min} \times \text{bore area (mm}^2) \times \text{stroke (mm)}}$$

$$\text{lbf/in}^2 = \frac{\text{bhp} \times 792000}{\text{Cylinders} \times \text{r/min} \times \text{bore area (in}^2) \times \text{stroke (in)}}$$

Torque

$$\text{Nm} = \frac{\text{kW} \times 9549}{\text{r/min}} \times \text{OL}$$

$$\text{lbf ft} = \frac{\text{bhp} \times 5252}{\text{r/min}} \times \text{OL}$$

OL = Overload
No overload = 1,0
10% overload = 1,1

Fuel Consumption

$$\text{l/h} = \frac{\text{g/kWh} \times \text{kW}}{839} \times \text{L}$$

$$\text{pt/h} = \frac{\text{lb/bhp h} \times \text{bhp}}{1{,}05} \times \text{L}$$

L = Load (naturally aspirated engines)

100% = 1,0	50% = 0.58
75% = 0,78	25% = 0.40

L = Load (turbocharged engines)

100% = 1,0	50% = 0.55
75% = 0,76	25% = 0.38

A Specific Gravity of 0.84 is assumed.

Oil Consumption

$$\text{l/24h} = \frac{\text{g/kWh} \times \text{kW}}{4661}$$

$$\text{pt/24h} = \frac{\text{lb/bhp h} \times \text{bhp}}{5{,}83}$$

Piston Speed

$$\text{m/sec} = \frac{\text{stroke (mm)} \times \text{r/min}}{30000}$$

$$\text{ft/min} = \frac{\text{stroke (in)} \times \text{r/min}}{6}$$

Mechanical Efficiency

$$\% = \frac{\text{bhp}}{\text{ihp}} \times 100$$

Cyclic Irregularity

$$\frac{\text{max flywheel speed} - \text{min flywheel speed}}{\text{mean flywheel speed}}$$

Power

$$\text{kW} = \frac{\text{r/min} \times \text{Torque(Nm)}}{9549}$$

$$\text{bhp} = \frac{\text{r/min} \times \text{Torque(lb ft)}}{5252}$$

Continuous Power

1bhp	= 1,014CV	= 0,746kW
1kW	= 1,340bhp	= 1,359CV
1CV	= 0,986bhp	= 0,736kW

Intermittent Power

1,1bhp	= 1,115CV	= 0,821kW
1,1kW	= 1,474bhp	= 1,495CV
1,1CV	= 1,085bhp	= 0,810kW

Appendix I

ISUZU DIESEL OF NORTH AMERICA, INC. ENGINEERING DEPARTMENT		MODEL SK NO.	C240PW28 ID-00-C010.00
BASIC ENGINE DESCRIPTION	2.4L, 4 CYL, 4 STROKE, WTR COOLED, OHV, I/L, INDIRECT INJECTED; NATURALLY ASPIRATED DIESEL B=86mm, S=102mm, CR=20:1, GLOW PLUG ASSISTED START		
ENGINE APPLICATION	ENCLOSED GENERATOR SET	ENGINE PERFORMANCE*	41 BHP@2000 RPM (GROSS INT) 36 BHP@1800 RPM (GROSS INT) 29 BHP@1500 RPM (GROSS INT)
SPECIFIC OEM INFORMATION	LIBBY MEP-804A	DATE OF ISSUE: 1/92	ORIGINAL DATE: 11/91 PREVIOUS ISSUE DATE:

SPECIFICATION INFORMATION

PART NAME	PART NUMBER	TYPE	PART DESCRIPTION
FLYWHEEL HOUSING	9-11341-630-1		SAE #4 w/FLAT SIDE MT PADS-148mm DEEP w/TACH PICKUP HOLE
OIL PAN	8-97036-771-A** 8-97036-770-A**	ASM BASIC	CTR SUMP CAP; 4.3L MAX 3.5L MIN LH DIP w/FILL BOT CTR DRAIN 30° INCL ALL DIR
DIP STICK	8-97043-925-A**		INSTALLED LH SIDE OF PAN MARKED FOR LEVEL WHEN RUNNING AND STOP
FLYWHEEL	5-12330-108-0 5-12331-105-0 5-12331-050-0	ASM FRONT REAR	2 PC, (FRT & RR), SAE 10" OVER CTR CLU w/DRIVE RING Z=108
CRANKSHAFT PULLEY	5-12371-090-1		1-GROOVE EFF DIA=137mm SPLINE TYPE w/PTO PROVISION
OIL FILTER	8-94128-854-1 8-94445-273-0	ASM ELEM	SYSTEM; FULL FLOW REPLACEABLE SPIN-ON PAPER ELEMENT TYPE FILTER @ ENG LWR RR RH SIDE
FUEL FILTER	9-13201-803-0 5-87810-039-0	ASM ELEM	REPLACEABLE PAPER CARTRIDGE TYPE FILTER @ ENG UPR FRT RH SIDE
WATER PUMP	5-13610-167-4	ASM	CENTRIFUGAL VANE TYPE-WATER INLET HRZ FLAT SLANTING TWD ENGINE FRT OD=35mm
WATER OUTLET PIPE	9-13713-038-0		UPWARD OUTLET OD=32mm
WATER INLET PIPE	N/A		INTEGRAL PART OF WATER PUMP
COOLING FAN	OEM SUPPLIED		455mm 7 BLADE PLASTIC BLOWER TYPE
FAN PULLEY	9-13641-616-2		1-GROOVE EFF DIA=102mm RATIO=1.35:1
SPACER FAN	9-13642-077-0		ALUMINUM t=26mm
OIL COOLER	N/A	ASM	
INLET MANIFOLD	9-14112-695-5		CTR UPWD INLET 2 M10x1.25 STUD FLANGE LOC ENG LH SIDE
EXHAUST MANIFOLD	9-14141-614-2		FRT UPWD OUTL 3 M10x1.25 STUD FLANGE LOC ENG LH SIDE
TURBOCHARGER	N/A	ASM	
EXHAUST ADAPTER	N/A		
MOUNTS	5-11771-022-0 5-11771-150-0	RH LH	L-TYPE INDUSTRIAL CAST IRON RH & LH UNIQUE

*Rating: SAE J1349

Engine Model Specification continued on the following page.

ISUZU INDUSTRIAL DIESEL ENGINE MODELS
0.65L THROUGH 2.8L DISPLACEMENT

ISUZU ENGINE MODEL		2KC1	3KC1	3KR1	3AB1	C240	4JB1
GENERAL ENGINE DESCRIPTION		4 CYCLE OHC IN-LINE WATER COOLED			4 CYCLE OHV IN-LINE WATER COOLED		
TYPE OF ASPIRATION		NATURAL					
TYPE OF INJECTION		INDIRECT					DIRECT
# OF CYLINDERS		2	3	3	3	4	4
BORE x STROKE	mm	74x76	74x76	81x92	86x102	86x102	93x102
DISPLACEMENT	LITER	0.65	0.98	1.4	1.8	2.4	2.8
COMPRESSION RATIO		23.0	23.0	20.0	20.0	20.0	18.2
ENGINE MODEL PERFORMANCE RATINGS							
GROSS RATED HORSEPOWER[1]	BHP/RPM	14.6/3000 16.4/3600*	23.0/3000 25.0/3600*	34.4/3000 35.1/3600*	41/2800	56/3000	70/3000
GROSS RATED PEAK TORQUE[1]	LB-FT/RPM	28/2000	44/2000	68/1800	80/2000	108/2000	132/2000
MINIMUM S.F.C.	LB/BHP-HR @RPM	.440/2500	.440/2200	.430/2200	.440/2200	.435/2000	.357/2200
NET INTERMITTENT RATED POWER PER SAE J1349 CONDITIONS @ SPECIFIC RPMs[2]	BHP/RPM	7.6/1500 9.2/1800 10.2/2000 12.1/2500 13.5/3000 15.1/3600	12.3/1500 14.8/1800 16.4/2000 19.5/2500 21.6/3000 23.5/3600	18.6/1500 22.4/1800 24.7/2000 29.1/2500 31.8/3000 32.4/3600	22/1500 27/1800 29/2000 32/2200 35/2500 38/2800	28/1500 35/1800 40/2000 43/2200 47/2500 52/3000	36/1500 44/1800 49/2000 53/2200 59/2500 67/3000
NET CONTINUOUS RATED POWER PER SAE J1349 CONDITIONS @ SPECIFIC RPMs[2]	BHP/RPM	6.8/1500 8.3/1800 9.4/2000 11.0/2500 12.0/3000 13.5/3600	10.8/1500 13.1/1800 14.6/2000 17.5/2500 19.5/3000 21.1/3600	16.4/1500 19.6/1800 21.8/2000 25.9/2500 28.4/3000 29.5/3600	19/1500 23/1800 26/2000 28/2200 31/2500 34/2800	25/1500 31/1800 34/2000 37/2200 42/2500 45/3000	31/1500 39/1800 43/2000 47/2200 52/2500 58/3000
NET PEAK TORQUE[2]	LB-FT/RPM	27/2000	42.6/2000	66/1800	77/2000	104/2000	129/2000
GENERAL ENGINE MODEL INFORMATION							
DIMENSIONS F/F (mm)	LENGTH WIDTH HEIGHT	469 502 591.5	554 489 608	626.5 483 697.5	716 527 722	800 535 694	805 600 730
DRY WEIGHT	KG	95	103	132	217	223	251
FAN TYPE & FAN DIAMETER	mm	SUCTION 320	SUCTION 320	SUCTION 360	BLOWER 380	BLOWER 380	BLOWER 380
ALTERNATOR SIZE	V-Amps	12-20	12-20	12-20	12-35	12-35	12-35
STARTER SIZE	V-kW	12-0.8	12-1.0	12-1.4	12-1.4	12-2.0	12-2.2
OIL PAN CAPACITY	LITER	2.7	4.0	5.0	4.8	4.3	5.5
COOLANT CAPACITY (BLOCK ONLY)	LITER	1.5	1.7	2.7	4.4	5.2	5.0
SUGGESTED BATTERY SIZE AND NUMBER	V-CCA No.	12-580 1	12-580 1	12-580 1	12-580 1	12-580 1	12-650 1

SPECIAL NOTATIONS

* 3600 RPM GEN-SET RATINGS SHOWN. FOR INDUSTRIAL USE AT 3600 RPM, CONTACT IDNA ENGINEERING FOR SPECIAL APPROVAL.

1 GROSS RATED CONDITIONS ARE WITHOUT FAN, MUFFLER OR AIR CLEANER AND CONFORM TO SAE J1349 STANDARDS. RATINGS ARE WITHIN +/-5%.

2 NET RATED CONDITIONS INCLUDE FAN, MUFFLER AND AIR CLEANER AND CONFORM TO SAE J1349 STANDARDS.

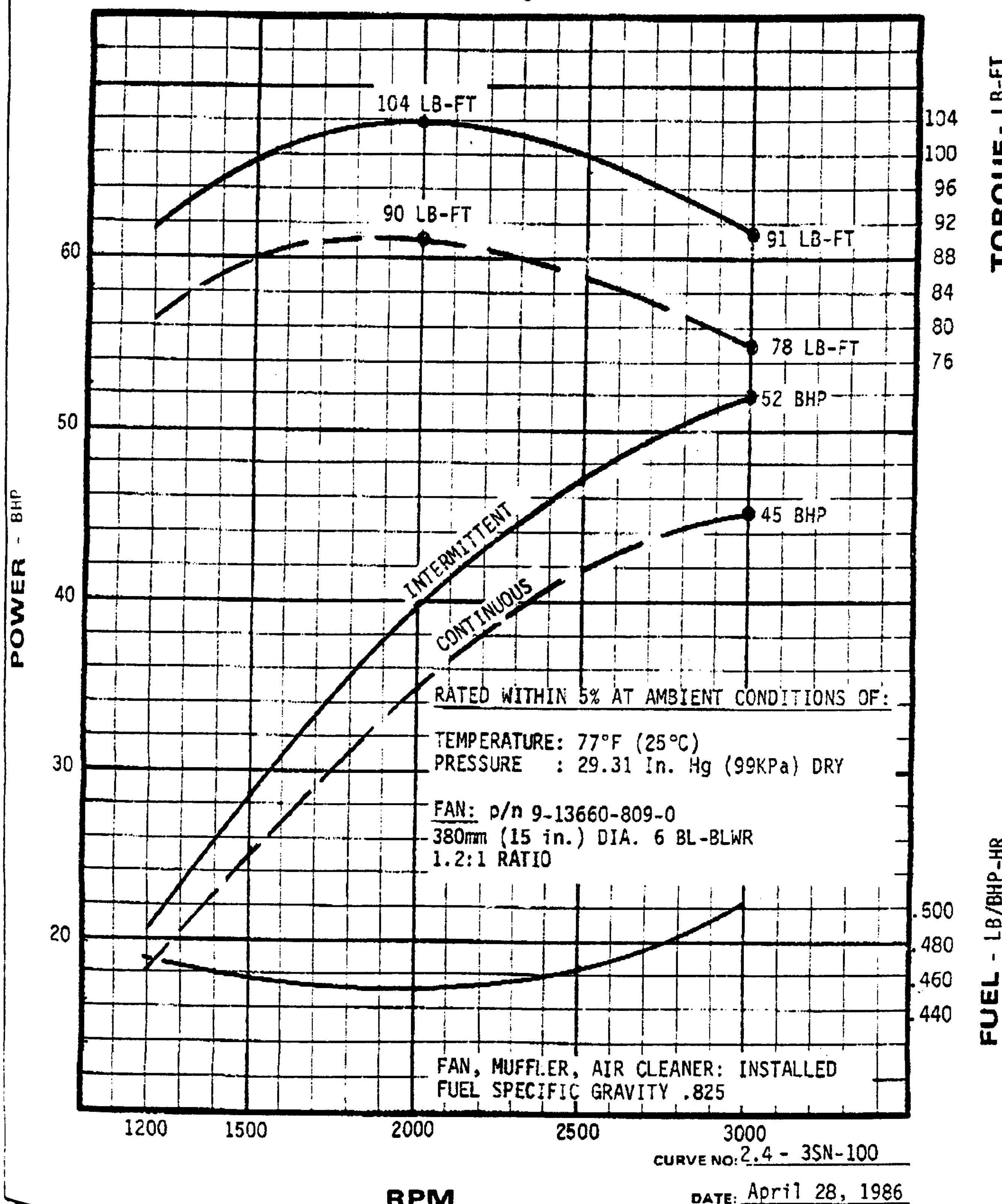
SPECIFICATIONS AND ENGINE PERFORMANCE RATINGS REFER TO STANDARD INDUSTRIAL ENGINE MODELS.

ISUZU DIESEL
OF NORTH AMERICA INC
NOVI, MICHIGAN

ISUZU DIESEL ENGINES

ENGINE PERFORMANCE

MODEL: **C240** (QD-60)
2.4L - 4 CYL.
APPLICATION: INDUSTRIAL
CONDITIONS: SAE J1349 - NET BHP



CURVE NO: 2.4 - 3SN-100

DATE: April 28, 1986

Appendix J

DETROIT DIESEL
CORPORATION

FACSIMILE TRANSMISSION

FROM: Mike Brogan – Vice President, Generator Set Power

Phone: (313)/592-5708 FAX: (313)/592-5158

Number of Pages (Including this one): 5 DATE: 6/30/94

TO: PETER SHAPIRO FAX: (913) 381-6189

RE: DETROIT DIESEL 4-71

WHAT WAS THE 4045C IS STILL BEING BUILT, BUT WE HAVE A NEW MODEL NUMBERING SYSTEM, AND NOW REFER TO IT AS A MODEL 1043-7005. THIS IS A NATURALLY ASPIRATED DETROIT DIESEL 4 CYLINDER SERIES 71 ENGINE (71 CU.IN. DISP/CYL)

POWER CURVE & SPECIFICATIONS ATTACHED.

AS A MANUFACTURER DDC ONLY SELLS TO OUR DISTRIBUTORS AND RECOGNIZED ORIGINAL EQUIPMENT MANUFACTURERS (OEM'S). FOR FURTHER INFO YOU SHOULD CONTACT GENE WAGNER AT CENTRAL DDA IN KANSAS CITY.

SINCERELY

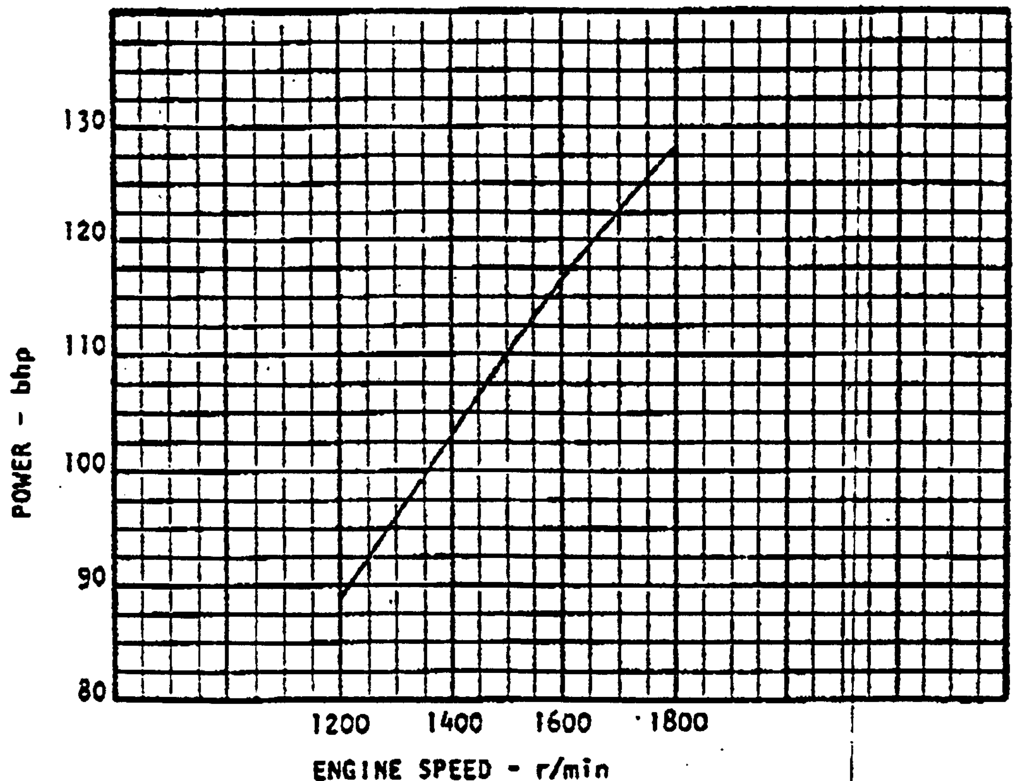
Mike Brogan

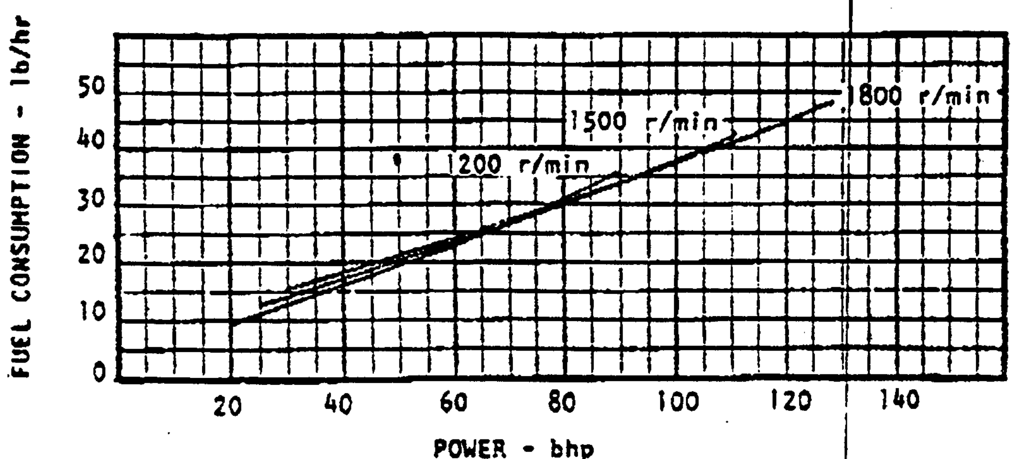
World Headquarters - 13400 Outer Drive, West / Detroit, Michigan 48239-4001 / Telephone: 313-592-5000 / Telex: 4320091 / TWX: 810-221-1649

DA 1

ENGINE PERFORMANCE CURVE

RATING: RATED BRAKE POWER APPLICATION: GENERATOR PRIME POWER	MODEL: 4-71N 128 bhp @ 1800 r/min 110 bhp @ 1500 r/min 89 bhp @ 1200 r/min





AIR INTAKE RESTRICTION - in. H_2O (kPa) . . . 10 (2.5)
EXHAUST BACK PRESSURE - in. H_2O (kPa). . . . 15 (3.7)

- POWER OUTPUT GUARANTEED WITHIN 5% AT SAE J1349 CONDITIONS: 77°F (25°C) AIR INLET TEMPERATURE; 29.31 in. Hg (99kPa) DRY BAROMETER; 100°F (39°C) FUEL INLET TEMPERATURE (.853 SPECIFIC GRAVITY AT 60°F).
- CONVERSION FACTORS: POWER: kW = bhp x 0.746
  FUEL: kg/hr = lb/hr x 0.454
- VALUES DERIVED ARE FROM CURRENTLY AVAILABLE DATA AND SUBJECT TO CHANGE WITHOUT NOTICE.

CERTIFIED BY:
STAFF ENGINEER

CURVE NO.
E4-1045-52-4
DATE: 10-28-80
REV./DATE: 1/5-17-85
SHT. 1 OF 4

ENGINE SPECIFICATION DATA

General Engine Description	
Model	104~~5~~3-7005
Number of Cylinders	4
Bore and Stroke-in(mm)	4.25x5.00(108x127)
Displacement-in^3(L)	284(4.66)
Compression Ratio	18.7:1
Valves per Cylinder	
Intake	NOT APPLICABLE
Exhaust	4
Combustion System	DIRECT INJECTION
Engine Type	INLINE - 2 CYCLE
Aspiration	NATURAL
Configuration	
Turbocharger	NOT APPLICABLE
Charge Air Cooling System	NONE
Blower Type	STANDARD
Blower Drive Ratio	2.00:1
Thrust Bearing Load Limit	
Continuous-lbf(N)	400(1780)
Intermittent-lbf(N)	1200(5340)
Engine Crankcase Vent System	OPEN
Maximum Pressure-in H_2O(kPa)	1.9(0.47)
Physical Data	
Dimensions and Weight	
Length-in(mm)	44.0(1118)
Width-in(mm)	29.4(746)
Height-in(mm)	46.4(1178)
Weight,dry-lb(kg)	1780(807)
Center of Gravity Distance	
From R.F.O.B. (x axis)-in(mm)	10.14(258)
Above Crankshaft (y axis)-in(mm)	7.25(184)
Right of Crankshaft (z axis)-in(mm)	0.47(11.9)
Installation Drawing	5147357
Maximum Allowable Static Bending Moment at Rear Face of FW Hsg-lbf ft(N m)	0
Electrical System	
Recommended Battery Capacity(CCA @ 0°F)	
12 Volt System	
Above 32°F(0°C)-A	950
Below 32°F(0°C)-A	1250
24 Volt System	
Above 32°F(0°C)-A	475
Below 32°F(0°C)-A	625
Max. Allowable Resistance of Starting Circuit	
12 Volt System - ohm	0.0012
24 Volt System - ohm	0.002

All values at rated speed and power and with standard engine hardware unless otherwise noted.

Curve No. E4-1045-52-4
Date: 10-28-80
Rev./Date: 1/5-17-85
Sht. 2 of 4

ENGINE SPECIFICATION DATA

	1800	1500	1200
Fuel System			
Fuel Injector/Timing	N60/1.460	N60/1.460	N60/1.460
Fuel Injection Pump/Timing	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE
Fuel Consumption-lb/hr(kg/hr)	48.4(22.0)	42.3(19.2)	35.4(16.1)
Fuel Consumption-gal/hr(L/hr)	6.9(26.2)	6.1(22.9)	5.1(19.2)
Fuel Spill Rate-lb/hr(kg/hr)	496.3(225.1)	468.3(212.4)	384.5(174.4)
Fuel Spill Rate-gal/hr(L/hr)	71(268.8)	67(253.6)	55(208.2)
Total Fuel Flow-lb/hr(kg/hr)	544.7(247.1)	510.6(231.6	419.9(190.5)
Total Fuel Flow-gal/hr(L/hr)	77.9(295.0)	73.0(276.5)	60.1(227.4)
Maximum Allowable Fuel Pump Suction			
Clean System-in Hg(kPa)	6(20)	6(20)	6(20)
Dirty System-in Hg(kPa)	12(41)	12(41)	12(41)
Fuel Filter Micron Size - Primary	30	30	30
Secondary	10	10	10
Lubrication System			
Oil Pressure - normal-lbf/in^2(kPa)	54(372)	50(345)	45(310)
In Pan Oil Temperature-°F(°C)	200-225(93-107)	200-225(93-107)	200-225(93-107)
Oil Flow-gal/min(L/min)	20(76)	17(64)	13(49)
Oil Pan Capacity - High-qt(L)	20(18.9)	20(18.9)	20(18.9)
Low-qt(L)	15(14.2)	15(14.2)	15(14.2
Total Engine Oil Capacity with Filters-qt(L)	22(20.8)	22(20.8)	22(20.8)
Bypass Oil Filter Orifice-in(mm)	0.062(1.57)	0.062(1.57)	0.062(1.57)
Engine Angularity Limits			
Front up - degrees	16	16	16
Front Down - degrees	16	16	16
Side tilt - degrees	NOT AVAILABLE	NOT AVAILABLE	NOT AVAILABLE
ling System			
..gine Heat Rejection-Btu/min(kW)	4020(70.7)	3520(62.0)	3200(56.3)
Engine Radiated Heat-Btu/min(kW)	790(13.8)	730(12.9)	680(11.9)
Coolant Flow-gal/min(L/min)	47(178)	40(151)	32(121)
Thermostat - Start to Open-°F(°C)	173(78)	173(78)	173(78)
Fully Open-°F(°C)	186(86)	186(86)	186(86)
Maximum Water Pump Inlet Restriction-in Hg(kPa)	3.0(10.2)	2.0(6.7)	1.0(3.4)
Engine Coolant Capacity-qt(L)	10.0(9.5)	10.0(9.5)	10.0(9.5)
Minimum Pressure Cap-lbf/in^2(kPa)	9.0(62.1)	9.0(62.1)	9.0(62.1)
Maximum Coolant Pressure (Exclusive of Pressure Cap)-lbf/in^2(kPa)	20(138)	20(138)	20(138)
Maximum Allowable Cooling System Static Head W/Vented Cap-ft H_2O(kPa)	50(149)	50(149)	50(149)
Maximum Top Tank Temperature-°F(°C)	210(99)	210(99)	210(99)
Minimum Top Tank Temperature-°F(°C)	163(73)	163(73)	163(73)
Min. Coolant Fill Rate-gal/min(L/min)	3.0(11.4)	3.0(11.4)	3.0(11.4)
Cooling Index			
Minimum Air to Boil-°F(°C)	117(47.2)	117(47.2)	117(47.2)
Maximum Air to Water Diff.-°F(°C)	95(52.8)	95(52.8)	95(52.8)
Deaeration - Air Injection Capacity-ft^3/min(m^3/min)	0.4(0.010)	0.4(0.010)	0.4(0.010)
Drawdown - Minimum Requirement (or 10% of Cooling System Capacity-Whichever is Larger)-qt(L)	4.0(3.8)	4.0(3.8)	4.0(3.8)

values at rated speed and power and with standard engine hardware unless otherwise noted.

Curve No. E4-1045-52-4
Date: 10-28-80
Rev./Date: 1/5-17-85
Sht. 3 of 4

ENGINE SPECIFICATION DATA

	1800	1500	1200
Air System			
Maximum Allowable Temperature Rise (Ambient Air to Engine Inlet)-°F(°C)...	30(16.7)	30(16.7)	30(16.7)
Air Intake Restriction Maximum Limit			
Dirty Air Cleaner-in H_2O(kPa).........	25(6.2)	18(4.5)	12(3.0)
Clean Air Cleaner-in H_2O(kPa).........	13.4(3.3)	11(2.7)	8.5(2.1)
Engine Air Flow - $ft^3/min(m^3/min)$......	380(10.8)	320(9.1)	260(7.4)
Engine Air Box/Manifold Pressure-			
In Hg(kPa)...........................	7.5(25.3)	5.0(16.9)	2.8(9.5)
Recommended Intake Pipe Dia.-In(mm)....	5.0(127)	5.0(127)	5.0(127)
Exhaust System			
Exhaust Flow-$ft^3/min(m^3/min)$...........	910(25.8)	760(21.5)	610(17.3)
Exhaust Temperature-°F(°C).............	820(438)	810(432)	785(418)
Maximum Allowable Back Pressure-			
In Hg(kPa)..........................	3.3(11.2)	2.3(7.8)	1.5(5.1)
Recommended Exhaust Pipe Diameter			
Single-In(mm)........................	3.5(89)	3.5(89)	3.5(89)
Dual-In(mm)..........................	NOT APPLICABLE	NOT APPLICABLE	NOT APPLICABLE
Performance			
Power Output-bhp(kW).................	128(95)	110(82)	89(66)
Full Load Speed-r/min................	1800	1500	1200
BMEP-lbf/in^2(kPa).....................	99.1(684)	102.6(707)	103.4(713)
Piston Speed-ft/min(m^3/min)............	1500(457)	1250(381)	1000(305)
Friction Power-bhp(kW)...............	29(22)	22(16)	16(12)
Altitude Capability-ft(m)............	16000(4880)	14000(4270)	12000(3660)
Noise - dB(A) @ 1m...................	99.7	98.2	96.9
Smoke - Bosch Number.................	1.7	0.9	1.0
Part Load Fuel Consumption			
Fuel-lb/hr(kg/hr) - 0% Power.........	8.5(3.9)	6.5(2.9)	5.0(2.3)
25% Power..........	16.3(7.4)	13.3(6.0)	10.5(4.8)
50% Power..........	25.5(11.6)	21.5(9.8)	17.7(8.0)
75% Power..........	35.8(16.2)	31.0(14.1)	25.4(11.5)
100% Power.........	48.4(22.0)	42.3(19.2)	35.4(16.1)

Emissions - gm/hr (at percent load) - 1800 r/min

	0%	25%	50%	75%	100%
NO_x	120	420	790	1300	1470
CO	83	44	41	116	1366
HC	50	48	46	47	50
SO_2	39	74	116	162	220

Emissions - gm/hr (at percent load) - 1500 r/min

	0%	25%	50%	75%	100%
NO_x	100	410	770	1230	1350
CO	78	36	33	71	1410
HC	41	39	38	39	42
SO_2	29	60	98	140	190

Emissions - gm/hr (at percent load) - 1200 r/min

	0%	25%	50%	75%	100%
NO_x	81	380	720	1100	1190
CO	71	30	25	36	1370
HC	33	31	30	31	35
SO_2	23	48	80	115	160

All values at rated speed and power and with standard engine hardware unless otherwise noted.

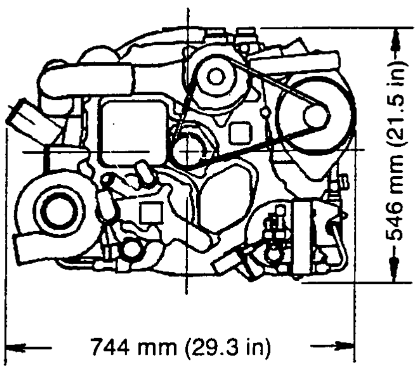
Curve No. E4-1045-52-4
Date: 10-28-80
Rev./Date: 1/5-17-85
Sht. 4 of 4

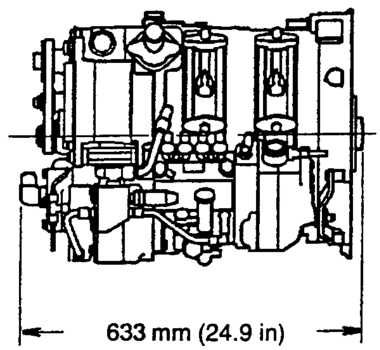
Appendix K

SCORE™ 70 SERIES ROTARY ENGINES

ROTARY POWER INTERNATIONAL, INC.

MODEL 2013R DIMENSIONS:

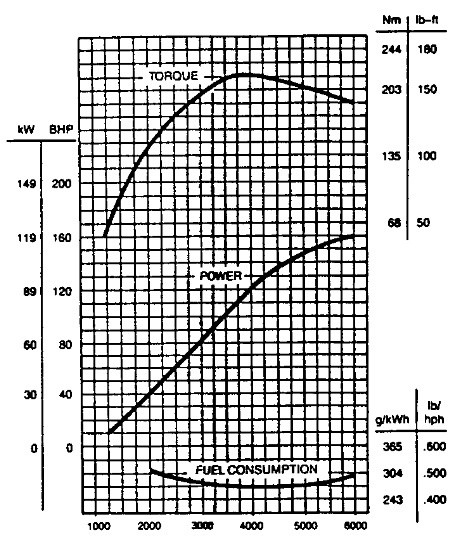




PERFORMANCE AND BRIEF SPECIFICATIONS FOR MODEL 2013R

2-rotor engine
Displacement—1.3L (80 in.^{3})

Weight—147 kg (325 lb.)
Rated power—120kW (160 bhp)
Rated speed—6000 rpm
Injection—direct
Ignition—spark
Compression ratio—8.5:1
Fuel—multiple fuel use (includes combat gasoline, CITE, JP4, JP5, JP8, No. 1 and No. 2 diesel fuel)
Turbocharger pressure ratio—2.0
Rotation—counterclockwise when viewed from flywheel end of engine



MODEL 2013R
ESTIMATED FULL LOAD PERFORMANCE

*For multi-rotor versions, power and torque increase in proportion to the number of rotors. Specific fuel consumption is the same.

ENGINE DESCRIPTION:

The SCORE 70 Series (**S**tratified **C**harge **O**mnivorous **R**otary **E**ngine) family of rotary engines is being developed for military and commercial use. Specific applications will dictate the availability of each model.

RPI's SCORE 70 Series family of rotary engines will offer power sizes in 1, 2, 3 and 4 rotor configurations (Dimensional drawings shown at left are for the two-rotor SCORE 70 Series model only. Other SCORE 70 models on back page.)

FEATURES:

All RPI rotary engines will offer these features:

Patented stratified charge, which allows SCORE engines to use a wide range of fuels
Exceptional power density
Low weight
Compact size
Excellent fuel economy
Design simplicity
High torque/high performance
Easy cold-weather start-up
High degree of parts commonality
Fewer parts
Modular construction
Low noise and vibration
Low magnetic signature

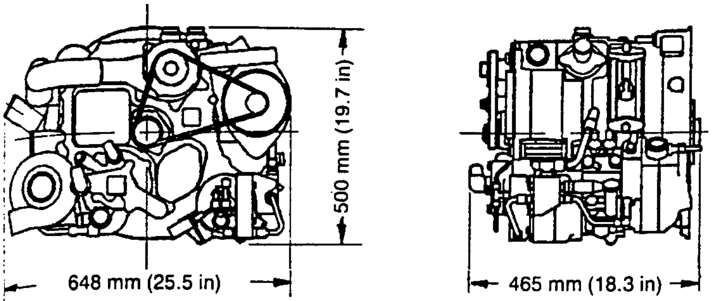
SCORE 70 (Continued)

THE SCORE 70 SERIES FAMILY OF ENGINES

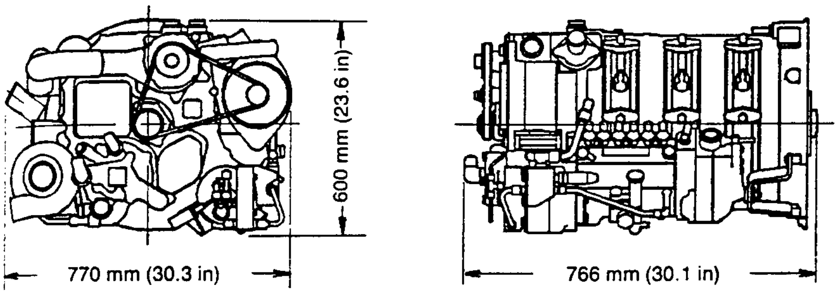
ROTARY ENGINE DIMENSIONS:

Envelope only, for vehicular applications. (Two-rotor version shown on front page) Dimensions for aircraft and generator set applications are available upon request.

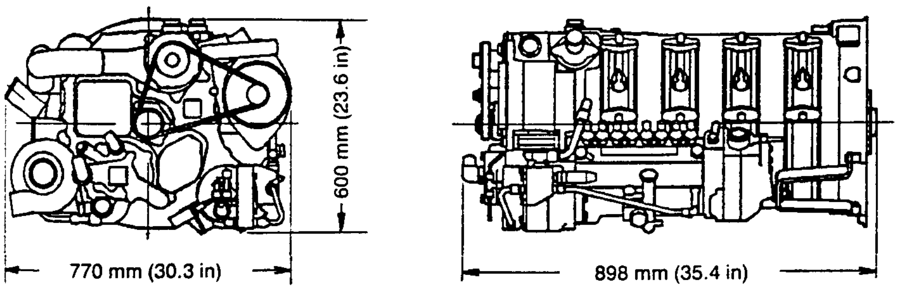
MODEL 1007R



MODEL 3020R



MODEL 4026R



SCORE 70 SERIES PERFORMANCE AND BRIEF SPECIFICATIONS:

Model No.	Number of Rotors	Displacement L (in.^{3})	Power kW (BHP)	Growth[1] Rating kW (BHP)	Volume m^3 (ft.^{3})	Weight kg (lb.)	Specific Weight[2] kg/kW	Specific Weight[2] lbs/hp
1007R	1	.7 (40)	60 (80)	120 (160)	0.151 (5.32)	123 (270)	2.05	3.38
2013R	2	1.3 (80)	120 (160)	240 (320)	0.257 (9.08)	147 (325)	1.23	2.03
3020R	3	2.0 (120)	180 (240)	360 (480)	0.353 (12.46)	200 (440)	1.11	1.83
4026R	4	2.6 (160)	240 (320)	480 (640)	0.415 (14.65)	240 (530)	1.00	1.66

Notes: [1]Power growth version availability estimated for 1995 and beyond.
[2]Values are for the near-term power. For growth versions, specific values will be one-half.

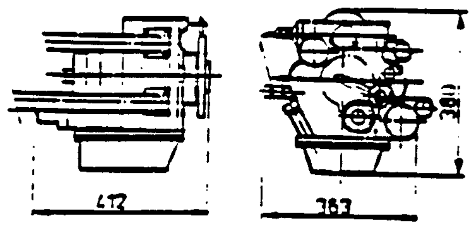
For more information about RPI SCORE rotary engines call 201/470-7004, or write Advanced Programs, Rotary Power International Inc., Box 128, Wood-Ridge, New Jersey 07075.

40 SERIES FAMILY OF ENGINES - "LOCR" MODELS

Heavy Fuel
Natural Aspirated and Turbocharged Versions

SINGLE ROTOR ENGINE

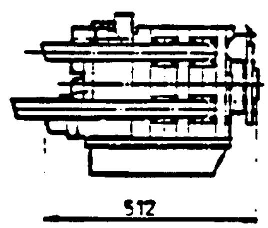
TYPE: LOCR - 407 SD*



SPEED	POWER**	
RPM	kW	HP
3000	10	14
3600	15	20
4500	18	24
6000	22	30
WEIGHT	KG	lbs
	36	79

TWIN ROTOR ENGINE

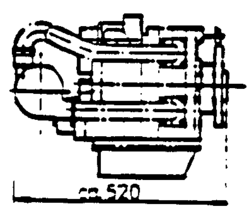
TYPE: LOCR - 814 TD*



SPEED	POWER**	
RPM	kW	HP
3000	20	24
3600	30	40
4500	36	48
6000	44	60
WEIGHT	KG	lbs
	50	110

SINGLE ROTOR TURBOCHARGED ENGINE

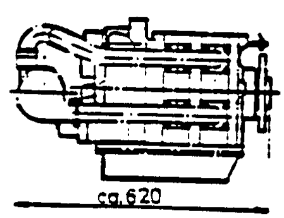
TYPE: LOCR - 407 SDT*



SPEED	POWER**	
RPM	kW	HP
3000	23	30
4000	30	40
5000	36	48
6000	37	50
WEIGHT	KG	lbs
	44	97

TWIN ROTOR TURBOCHARGED ENGINE

TYPE: LOCR - 814 TDT*



SPEED	POWER**	
RPM	kW	HP
3000	45	60
4000	60	80
5000	72	96
6000	75	100
WEIGHT	KG	lbs
	60	132

*SD =SINGLE DIESEL
*TD =TWIN DIESEL
*SDT =SINGLE DIESEL TURBO
*TDT =TWIN DIESEL TURBO
*LOCR =LIQUID & OIL COOLED ROTARY
** POWER ON DF-2 FUEL

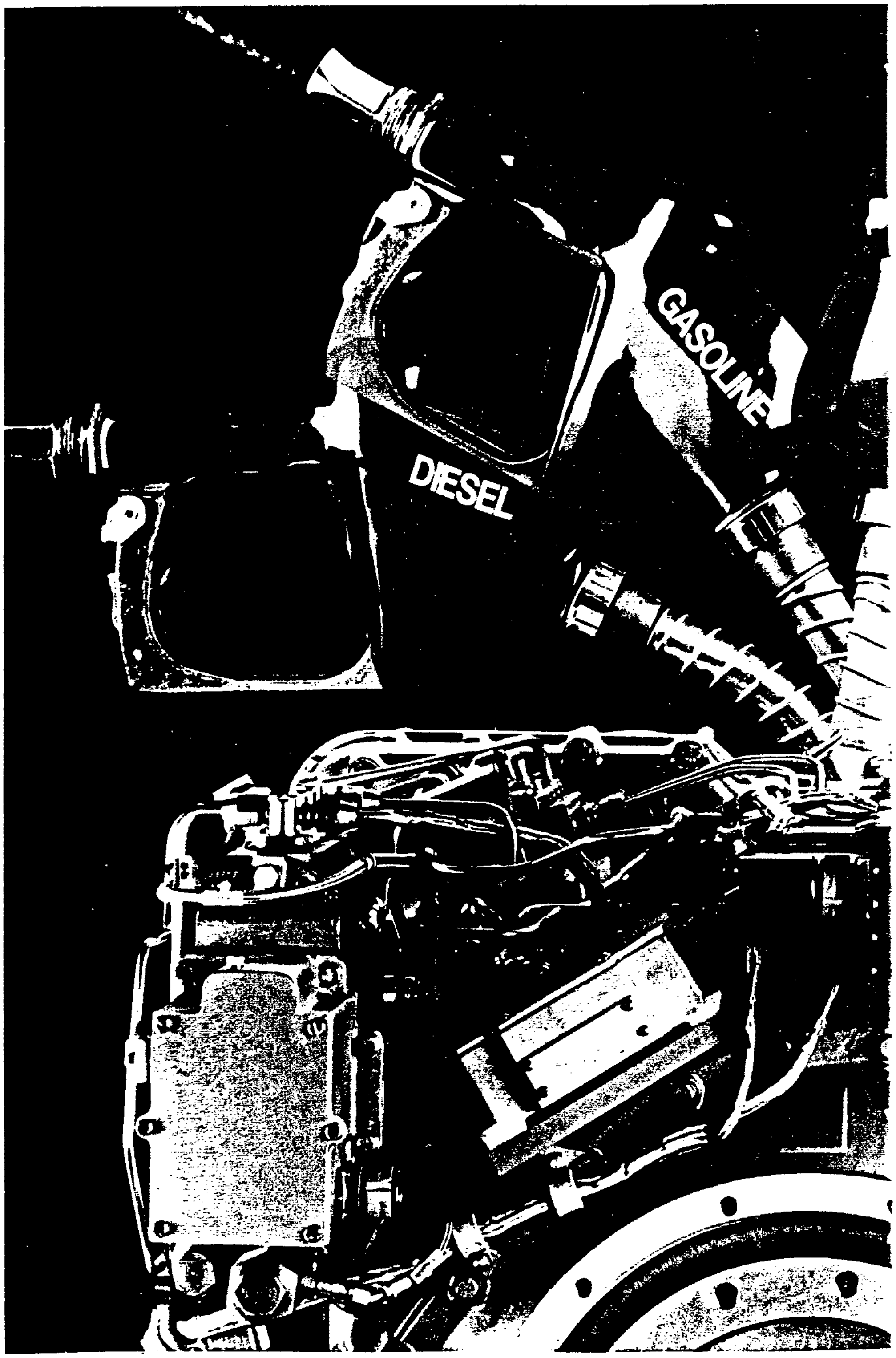
1995

A dependable po
afford to be fini

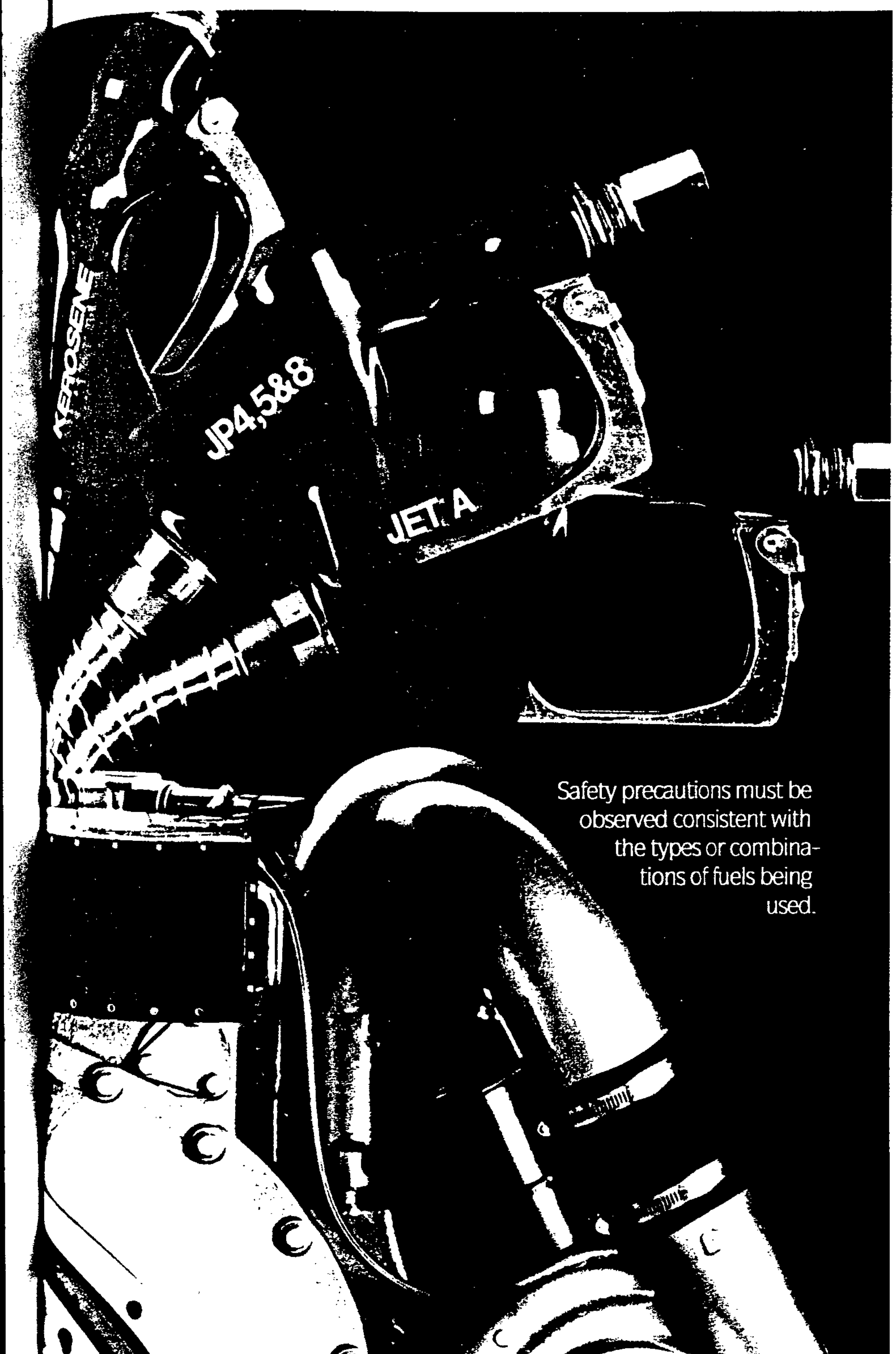
The SCORE rotary engine is not finicky when it comes to different types of fuel it can use. Thanks to a patented stratified charge injection system, a wide variety of fuels (including diesel, JP4, JP5, JP8, gasoline, kerosene and Jet A) can be used. The fuel-efficient system lets you use almost any available fuel . . . an omnivorous feature that is an important factor in logistics planning. This means that fighting men can use any fuel, including captured enemy stores. And that just may help achieve tactical superiority.

To create this layered or stratified burn, the pilot injector injects a small amount of fuel that is ignited by an electrically energized source. This creates a pilot flame which then ignites a larger amount of fuel injected by the main injector. As the rotor sweeps past the injectors, a layered (stratified) charge is maintained. This stratification across the entire operating range is inherent in SCORE engines. (Compare this natural motion to stratified charge piston engines that require forced swirl or other power stealing features.)

Turbocharging SCORE engines provides good fuel consumption (equivalent to diesel) by permitting operation at very low overall fuel/air ratios. Idle fuel consumption is extremely good. Cold weather start-up is easy. Also, low noise levels, low vibration, and almost no black smoke help reduce the chance for detection . . . important pluses for any operation.

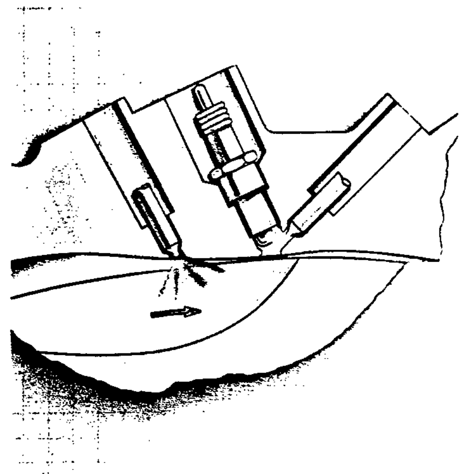


wer source can't cky about fuel



Safety precautions must be observed consistent with the types or combinations of fuels being used.

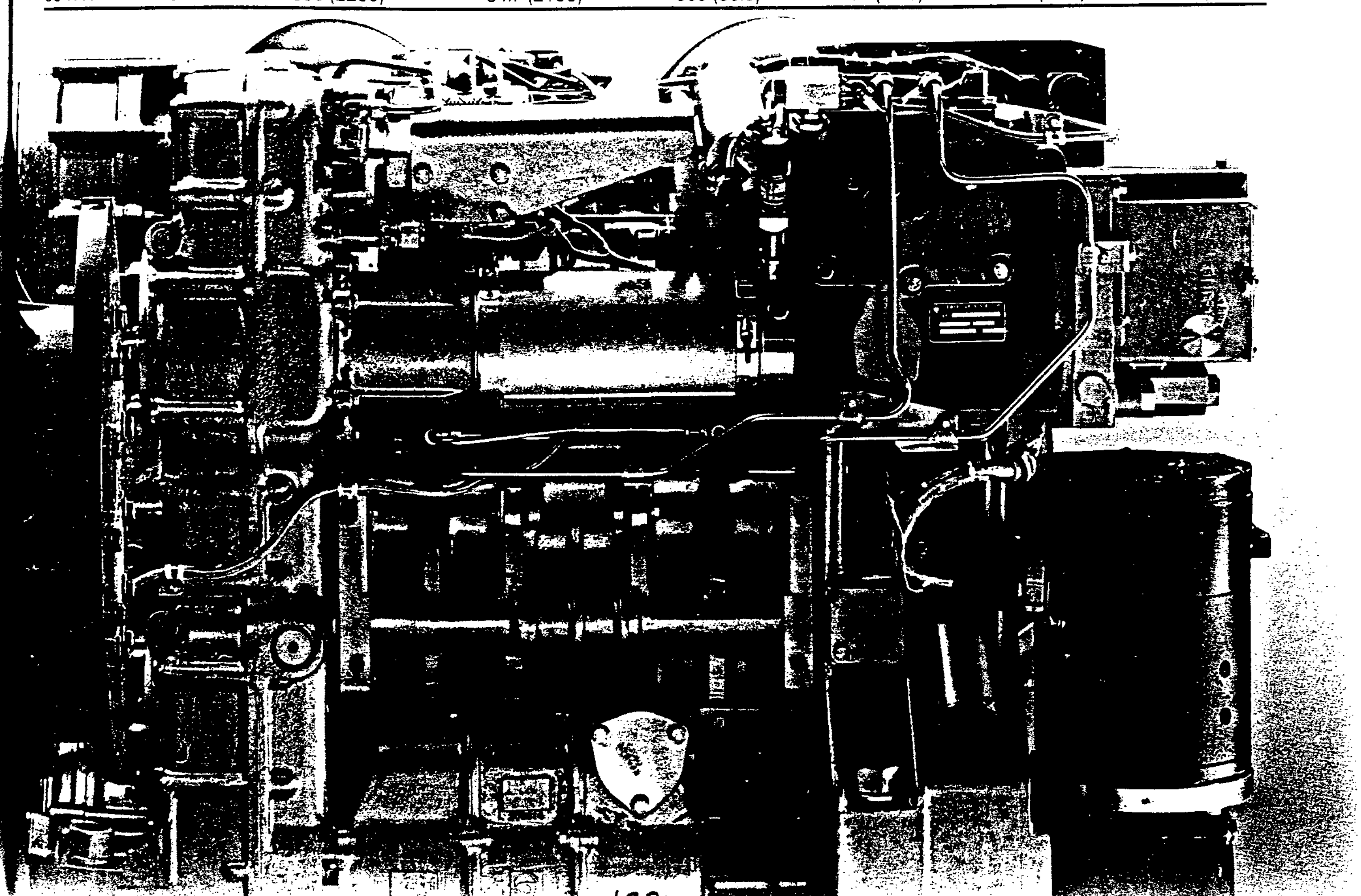
The patented stratified charge system used on all SCORE engines helps to make these engines omnivorous and fuel efficient. This enables you to use a wide variety of fuels including diesel, JP4, JP5, JP8, gasoline, kerosene and Jet A.



This schematic diagram shows the relationship between the two injectors and the spark plug in the stratified charge injection system.

eup of rotary engines

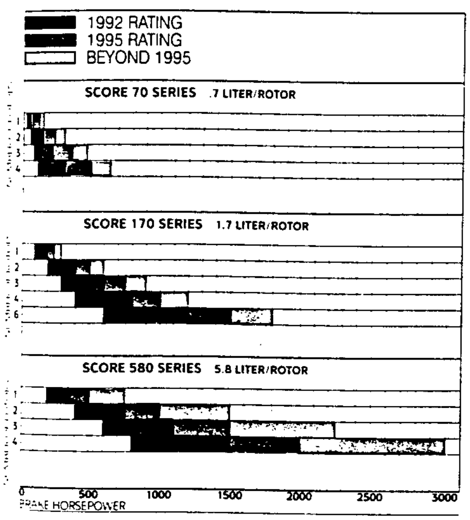
Model	No. of Rotors	Power kW (bhp)	Displacement L (in³)	Height mm (in.)	Width mm (in.)	Length mm (in.)	Weight kg (lb.)
1007R	1	60 (80)	.7 (40)	500 (19.7)	648 (25.5)	465 (18.3)	123 (270)
2013R	2	120 (160)	1.3 (80)	546 (21.5)	744 (29.3)	633 (24.9)	147 (325)
3020R	3	180 (240)	2.0 (120)	600 (23.6)	770 (30.3)	766 (30.1)	200 (440)
4026R	4	240 (320)	2.6 (160)	600 (23.6)	770 (30.3)	898 (35.4)	240 (530)
1017R	1	150 (200)	1.7 (105)	610 (24.0)	762 (30.0)	699 (27.5)	220 (485)
2034R	2	300 (400)	3.4 (210)	610 (24.0)	762 (30.0)	874 (34.4)	280 (617)
3051R	3	450 (600)	5.1 (315)	610 (24.0)	812 (32.0)	1050 (41.3)	350 (772)
4068R	4	600 (800)	6.8 (420)	610 (24.0)	812 (32.0)	1250 (49.2)	435 (959)
6102R	6	900 (1200)	10.2 (630)	610 (24.0)	812 (32.0)	1625 (64.0)	575 (1268)
1058R	1	280 (375)	5.8 (350)	848 (33.4)	1043 (41.0)	859 (33.8)	580 (1279)
2116R	2	560 (750)	11.6 (700)	848 (33.4)	1043 (41.0)	1107 (43.6)	771 (1700)
3174R	3	840 (1125)	17.4 (1050)	848 (33.4)	1134 (44.7)	1348 (53.1)	1048 (2310)
4231R	4	1120 (1500)	23.1 (1400)	848 (33.4)	1134 (44.7)	1590 (62.6)	1234 (2720)
5290R	5	1400 (1875)	29.0 (1750)	889 (35.0)	1194 (47.0)	1831 (72.1)	1511 (3331)
6347R	6	1680 (2250)	34.7 (2100)	889 (35.0)	1194 (47.0)	2073 (81.6)	1633 (3600)



Plan to include SC
in your

The SCORE families of rotary engines promise exceptional benefits for land, sea and air applications. With RPI's manufacturing capabilities and the SCORE rotary engine potential in a wide variety of applications they will become an important part of this nation's defense. And, in comparison to other power plants under development, a SCORE rotary engine is significantly smaller and lighter than any regenerated turbine or adiabatic diesel presently projected within comparable time frames.

For your convenience, this chart summarizes the SCORE rotary engine power range today . . . and tomorrow.



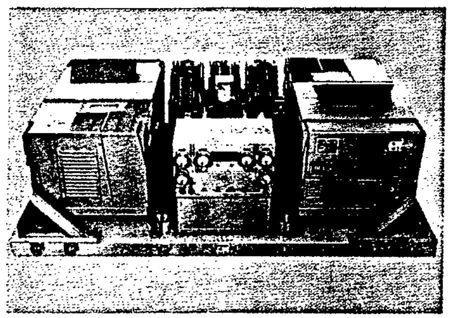
FOR VEHICULAR APPLICATIONS

SCORE engines wil offer your vehicles a lower profile, thereby reducing target size and armor. Or, they will help open up more space for ammunition and personnel.

The many benefits of a SCORE rotary engine (including excellent start-up, low detectability, high power density and omnivorous capability) make it desirable for heavy tanks, infantry fighting vehicles, self-propelled guns, tactical trucks, and engine/generator sets.

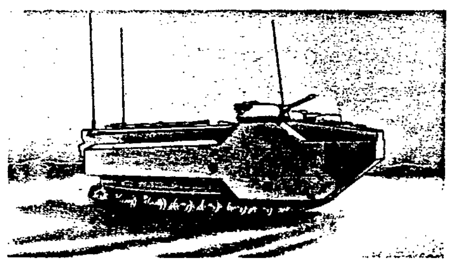
This FMC test vehicle is a good demonstration of improved performance from a high power density SCORE rotary engine.

ORE rotary engines designs



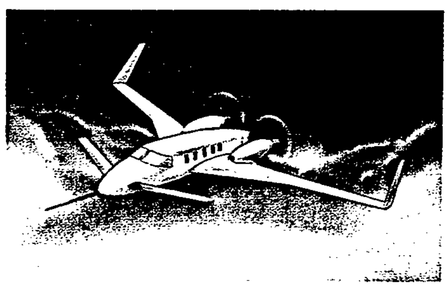
FOR POWER GENERATION

Because SCORE rotary engines have the weight characteristics of a turbine, coupled with diesel engine cost and fuel economy, they assure optimum usefulness in power generation applications. Also, a SCORE engine's low noise and vibration characteristics make it a candidate for "quiet" generator sets.



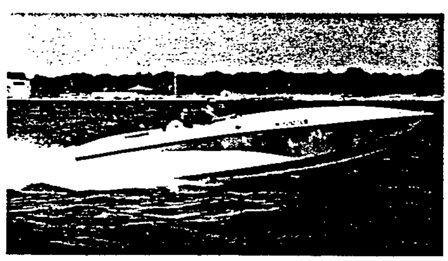
FOR AMPHIBIOUS APPLICATIONS

Consider SCORE rotary engines as the ideal power plant for amphibious craft... especially where high speed, shallow draft and reserve buoyancy are required.



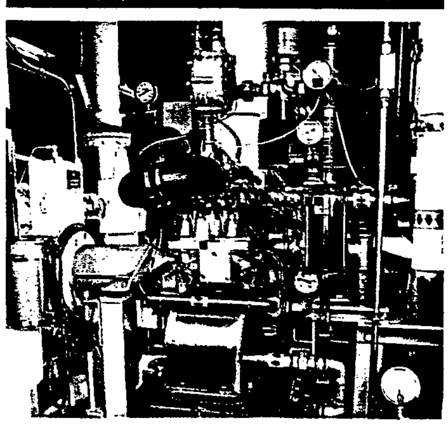
FOR AIRCRAFT APPLICATIONS

For light aircraft, a number of SCORE engine advantages are recognized by NASA and airframe manufacturers. These are Jet A fuel capability, smaller size, lower weight, reduced frontal area and parasitic drag, improved fuel efficiency, lower operating cost and attractive retrofit performance and economics.



FOR MARINE APPLICATIONS

The reduced weight and compact size will help reduce bow-down tendency and improve mean draft of vehicles. These advantages overcome the size-weight penalties of the diesel engine and the fuel and air consumption problems of the gas turbines.



INDUSTRIAL-NATURAL GAS

Natural gas conversions of the SCORE rotary engine can meet the needs of many industrial applications including cogeneration, power generation, coincident peak shaving, air compressors, chiller compressors, and, eventually the demanding needs of the oil and gas and irrigation industries.

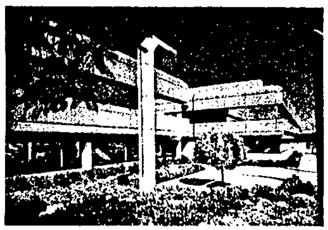
Appendix L

Auxiliary Power with Proven Performance

For over 35 years, Sundstrand Corporation's Power Systems Division has focused its technology on small gas turbine engine Auxiliary Power Units (APUs), manufacturing over 18,000 gas turbine engines with 35,000,000 accumulated service hours.

Sundstrand Corporation has formed a joint corporation, Auxiliary Power International Corp. (APIC) with Labinal S.A. (France.) APIC is located in San Diego, California and markets, sells and supports commercial aircraft auxiliary power units worldwide. The company will capitalize on the experience and expertise of Sundstrand and Labinal to address worldwide opportunities in the commercial aircraft market.

The APS 2000 entered service aboard the Boeing 737 aircraft in mid-1991. It has been selected by the largest 737 operators in the United States, Europe and Asia. APIC's next engine program, the APS 3000 for the Airbus A321 and A320 aircraft, will enter service in early 1994.



The APS 1000 APU is currently in service aboard the Fokker 50 aircraft and the Saab 2000. The simple and reliable APS 500 APU has proven itself in such varied applications as the Citation 6 and 7, deHavilland Dash 8, BAe 125 and Embraer 120.

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Military Applications

Sundstrand Power Systems produces reliable compact and lightweight military gas turbine auxiliary power units for numerous applications including fixed and rotary wing aircraft and assault landing craft. Sundstrand is also developing a series of small expendable thrust engines.

Auxiliary power units are available to both OEM's and packagers. Mobile ground power systems are also available in association with MAK System GmbH, Kiel, Germany.

Sundstrand Power Systems Customer Support

Sundstrand's commercial and military APUs are supported by: Sundstrand Aerospace's worldwide field service network, Product Support Organization and Integrated Logistics Support Department. All Sundstrand Power Systems' products are tested against tough quality assurance standards — ensuring the highest levels of quality, performance and reliability.

SPS San Diego, California
619/627-6306
Fax 619/627-6400

APIC San Diego
619/492-5902
Fax 619/492-5900

Product Support San Diego
619/495-9512

Los Angeles, California
213/670-0231

Cupertino, California (San Francisco)
408/973-7812

Redmond, Washington (Seattle)
206/453-1393

Arlington, Texas (Dallas)
817/640-1834

Dayton, Ohio
513/461-3232

St. Louis, Missouri
314/569-9840

Arlington, Virginia (Washington, D.C.)
703/276-1626

Atlanta, Georgia
404/761-2832

Power Systems | SUNDSTRAND AEROSPACE
SAN DIEGO CALIFORNIA 92186 Sundstrand Corporation

4400 RUFFIN ROAD • P.O. BOX 85757 • SAN DIEGO, CA 92186-5757
PHONE (619) 627-6000 • FAX (619) 627-6641

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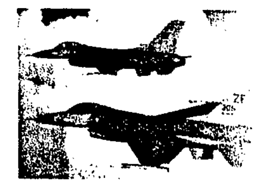
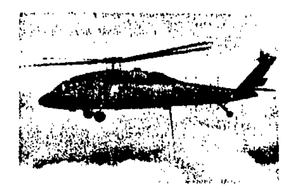
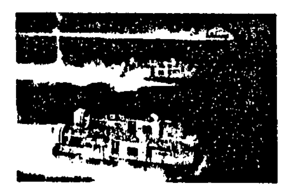
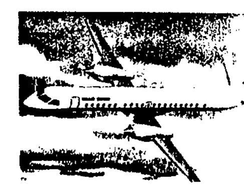
Auxiliary and Ground Power Systems

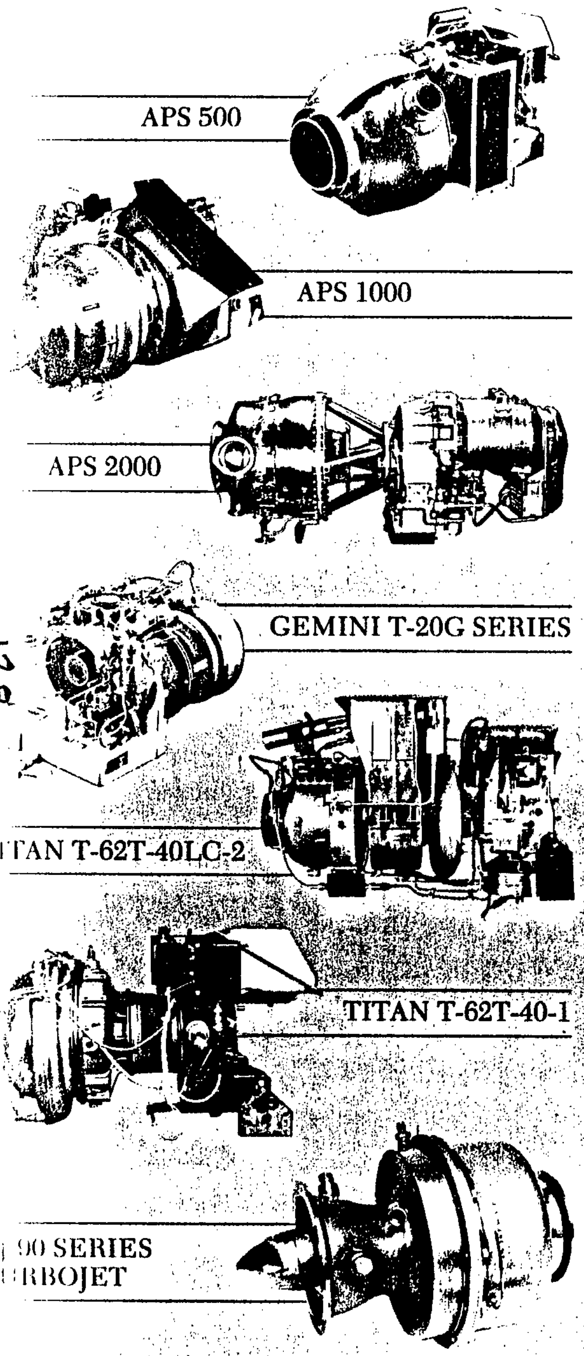








Power Systems | SUNDSTRAND AEROSPACE
SAN DIEGO CALIFORNIA 92186 Sundstrand Corporation



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…l-trand Power Systems commercial APUs are marketed by …liary Power International Corporation.

MODEL SUMMARY

	APIC MODEL	SPS DESIGNATION	STANDARD DAY PERFORMANCE Max. Bleed Air (PPM)	Max. Shaft Output (HP)	Thrust (LBS)	SIZE (IN.) LxWxH	DRY WEIGHT (LBS.)
MILITARY APPLICATION		T-20G-10C1	16	28		24.4 x 13 x 13.7	70
		T-20G-10C3/4	0	28		24.4 x 13 x 13.7	70
		T-20G-10-1	5	13		24.4 x 13 x 13.7	62
		T-20G-10C4P	0	28		12.9 x 12.5 x 9.8	28 *
		T-62T-2A1	0	95		31.4 x 18.5 x 18	71
		T-62T-2B	0	95		32.7 x 13.8 x 21.1	75
		T-62T-11	0	75		26.8 x 14 x 19.4	70
		T-62T-11A	0	47		26.2 x 15.6 x 15.9	95
		T-62T-16B1	0	75		26.9 x 15.4 x 18.4	75
		T-62T-27	0	140		27.0 x 17.2 x 22.5	83
		T-62T-32/A	0	90		33.7 x 20 x 21.5	155
		T-62T-39	37	40		29.8 x 20.9 x 21.2	97
		T-62T-40-1	72	90		29.3 x 16 x 17.1	87
		T-62T-40-7	40	150		38.2 x 21.5 x 21.5	164
		T-62T-40-8	0	230		17.2 x 13.9 x 13.9	50 *
		T-62T-46-1	52	300		29 x 16.4 x 16	132
		T-62T-40LC-1	150	0		41 x 31.4 x 23.6	277
		T-62T-40LC-2	150	40		38.8 x 23 x 24.5	169
		T-62T-40LC-3	150	120		52.8 x 25.9 x 26.9	316
		T-62T-47-1	150	280		48.6 x 20.4 x 28.7	225
		TJ-50			50	7.25 x 4.0 x 4.0	6
		TJ-90			107	9.25 x 6.2 x 6.2	10.5
COMMERCIAL APPLICATION	APS 500	T-62T-40C3A1	76	60		31.6 x 16.2 x 20.1	87
	APS 500	T-62T-40C7B	72	87		31.6 x 16.2 x 18.2	103
	APS 500	T-62T-40C7E1	57	95		29.0 x 19.0 x 18.9	108
	APS 500	T-62T-40C7E2	70	90		29.0 x 19.0 x 19.0	102
	APS 500	T-62T-40C8D1	40	40		27.8 x 19.0 x 21.5	96
	APS 1000	T-62T-46C1	97	150		33.6 x 20.5 x 20.6	175
	APS 1000	T-62T-46C7	83	90		39.2 x 23.0 x 26.0	160
	APS 2000	T-62T-47C1	175	95		42.1 x 20.9 x 21.9	270
	APS 3000		200	170		49.0 x 33.5 x 30.0	300

Note: Maximum bleed air and shaft loads shown are not concurrent. * Powerhead only

APPLICATION SUMMARY

	MODEL	APU APPLICATION	MODEL	APU APPLICATION
MILITARY AIRBORNE	T-62T-2A1	CH-47 A-C Helicopter	T-62T-40-1	Black Hawk, Seahawk and Night Hawk Helicopters
	T-62T-2B	CH-47D Helicopter	T-62T-40-8	Jet Fuel Starter for F-16 Fighter Aircraft
	T-62T-11	CH-46 Helicopter	T-62T-46-1	V-22 Osprey
	T-62T-16	VH-3D Presidential Helicopter	T-62T-40LC-2	KC-135R (Dual Installation)
	T-62T-16A2	CH-54 Helicopter	TJ-50	Turbojet for Unmanned Vehicles and Tactical Missiles
	T-62T-27	CH-53E Helicopter	TJ-90	Turbojet for Unmanned Vehicles and Tactical Missiles
	T-62T-16B	CH-3C Helicopter		
COMMERCIAL AIRBORNE	T-20G-10C3	Learjet 55B, King Air	T-62T-40C8D	BAe125-800
	T-62T-39	Falcon 20, JetStar, HS-125 & Sabreliner	T-62T-46C	Fokker 50
	T-62T-40C	JetStar, HS-125-700, Falcon 20 & Sabreliner	T-62T-40C3A1	Citation VI, VII
	T-62T-40C2	Gulfstream G-II and JetStar	T-62T-40C7B	deHavilland Dash8–100/300
	T-62T-40C3	Falcon 200	T-62T-40C7E1	Embraer 120
	T-62T-40C3A	Falcon 50	T-62T-40C7E2	Falcon 20
	T-62T-40C4	Fokker F-27	T-62T-40C8D1	BAe 125-800/1000
	T-62T-40C7	deHavilland Dash 7	T-62T-46C7	Saab 2000
	T-62T-40C7A	Cessna Citation III	APS 2000	Boeing 737
	T-62T-40C7D	deHavilland Dash 8 100 Series	APS 3000	A320/A321
GROUND AND MARINE POWER	T-20G-10C1	IPECS (Integrated Power & Environmental Control System)	T-62T-32-1	CNR Hydrofoil Generator, 400-Hz
			T-62T-32-2	60-kW, 60-Hz Generator Set
	T-20G-10C4	15-kW Generator Set	T-62T-32-3A	Generator Sets and Hydrostarter
	T-62T-11A	PPU for CF-LLADS (Canadian Forces Low Level Air Defense System)	T-62T-32A	60-kW, 400 Hz Generator Set for Patriot and GLCM
			T-62T-40-7	LCAC (Landing Craft Air Cushion) Vehicle
	T-62T-32	30/60 kW, 400 Hz Generator Set	T-62T-40LC-1	Ground Start Unit

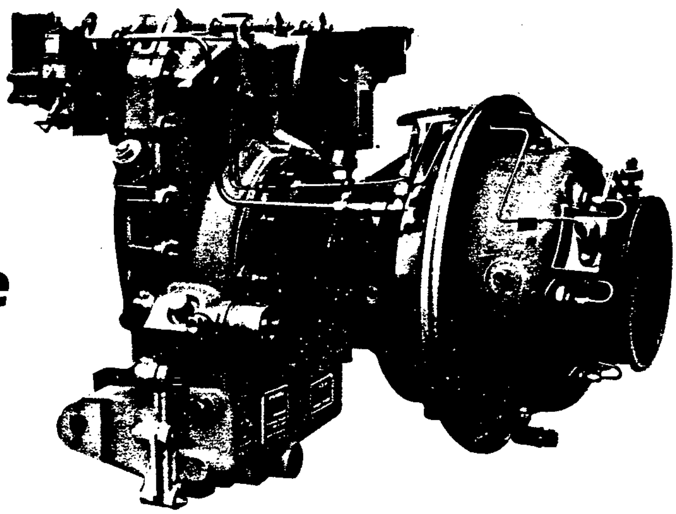
SUNDSTRAND SHAFT POWER GAS TURBINES FOR GENERATOR SETS

MODEL	POWER Sea Level 125°F	STATUS	COMMENTS
Gemini® T-29G -10	Up to 22 shp	Production Available	12,000rpm Under armor and airborne 3,600rpm
Titan® T-62T-40 Series	Up to 100kW	Production Production Available	6,000rpm Textron LCAC Hovercraft 8,000rpm PG Hydrofoil Japan 3,6000rpm
Titan® T-62T-32A	Up to 60kW	Available	Has lowest sfc. Now out of production, but could be revived if quantities merit.
T-46	Up to 150kW	In Development	Gas turbine from V-22 APU. Generator drive gearbox under evaluation
T-47	Up to 250kW	Production	From APS 2000 APU in Boeing 737. Generator drive gearbox under evaluation

Model T-62T-32A

TITAN®

Gas Turbine Engine



Technical Data

Rating
Flat Rated at 90 shp (60 kW)*

Fuel Consumption 15°C [59°] Sea Level
34.9 kg/hr (77 lb/hr) (max.) at Rated Output Power

Rotor Speed
Nominal 72,226 rpm

Output Pads
Axial Pad 6000 rpm CW
AND 20006 Type XVI B

Maximum Continuous Temperature
704°C (1300°F) EGT

Dry Weight
180 lb

Operating Environment
Operation up to 5000 ft. and 107°F (41.7°C) and at 8000 ft. at an ambient temperature of 95°F (35°C) the unit shall provide 90% of rated load.
Temperature: −65°F (−54°C) to 125°F (52°C) at Sea Level.

Fuels
MIL-J-5624 (JP 4 & 5)
VV-F-800 (Diesel)
MIL-G-5572 (Aviation Gasoline)
MIL-J-5161 (Jet Fuel)
MIL-T-831333 (JP: Turbine Fuel)

Oils
MIL-L-7808
MIL-L-2104 Grade 10

TBO
6000 Design MTBO

Standard Features

- Integral Oil System, External Oil Cooler
- Single-Stage Radial Compressor
- Single-Stage Radial-Inflow Turbine
- Cold End Drive
- Annular Combustor with Air Atomizer
- Starts within 60 Seconds from −54 to 54°C (−65 to 130°F)
- Operating Attitude +5° Fore, Aft, Either Side
- Overspeed Protection Speed Switch
- Overtemperature Protection Thermocouple
- Low Oil Pressure Protection Switch
- High Oil Temperature Protection Switch
- Starter: 24 VDC System

Power Systems | SUNDSTRAND AEROSPACE
4400 RUFFIN ROAD • SAN DIEGO, CA 92186-5757

APU

Technical Data

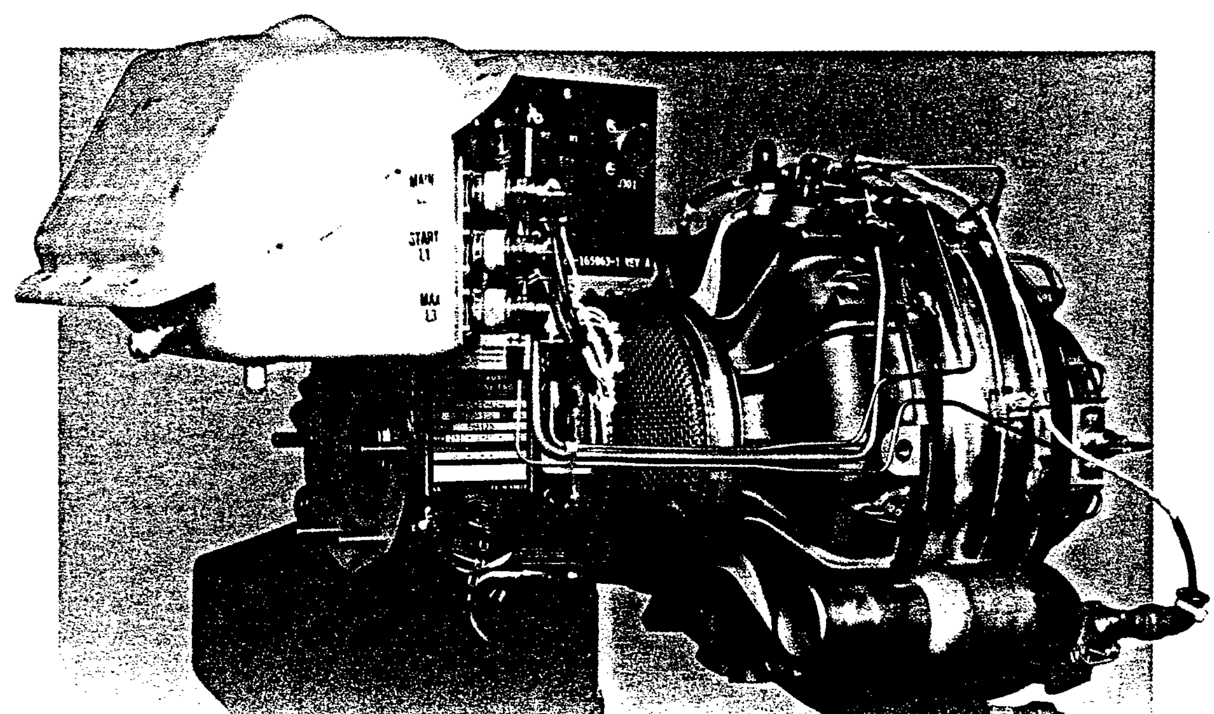
- **Minimum Rating at 59°F, (15°C) Standard Day, Sea Level:**
  Zero shp: 72 ppm bleed, 3.45:1 Pressure Ratio
  Zero Bleed: 90 shp
- **Rated EGT:**
  649°C (1200°F)
- **Operating Envelope:**
  Temperature: −54°C (−65°F) to 54°C (130°F)
  Altitude: Start & Operate to 20,000 ft. (32,000 km.)
- **Weight:**
  Basic APU, Including Gearbox – 84 lbs. (38.18 kg.)
  ESU – 4.8 lbs. (2.18 kg.)
- **Fuels:**
  MIL-J-5624 (JP-4 & JP-5), ASTM-D1655, or Commercial Equivalent
- **Oils:**
  MIL-L-7808, MIL-L-23699, or Commercial Equivalents
- **Output Pads:**
  One Modified AND 20002, Type XII-A Pad, (12,000 rpm)
  One AND 20001, Type XI B Pads (8216 rpm)
- **Maximum Fuel Consumption:**
  70.45 kg/hr. (155 lb./hr.)
- **TBO:**
  3,000 cycles
- **Specifications:**
  APU: MIL-P-8686
  ESU to MIL-STD-462

Standard Features

- Integral Oil System
- Acceleration Control
- Fully Automatic Control System for Start & Operation
- Microprocessor, Solid State Sequencer
- Single Stage Radial Compressor
- Single Stage Radial Inflow Turbine
- Cold End Thrust & Radial Bearings
- Annular Combustor with Air Atomizer
- Starts within 4 to 30 Seconds from −54°C (−65°F)
- Installation Attitude: 15° Fore, Aft, Either Side
- Operating Attitude: 45° Fore, Aft, Either Side
- Overspeed Protection
- Overtemperature Protection
- High Oil Temperature Protection
- Bleed Venturi
- Start Counter, Engine Mounted
- Hourmeter, Engine Mounted

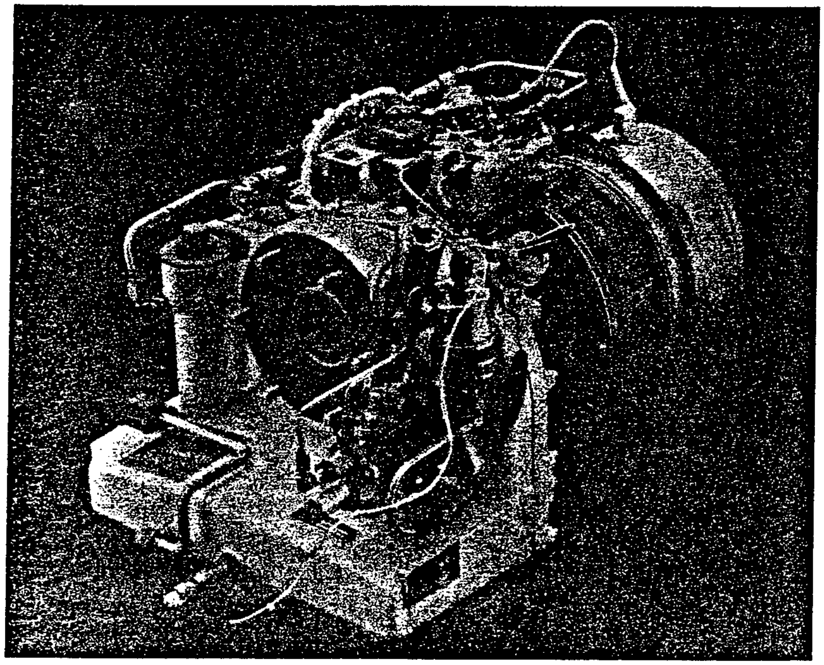
Standard Components

- Oil Pump
- Fuel Filter
- Ignition System
- Fuel Control
- EGT Thermocouple
- Oil Pressure Regulator
- Oil Pressure Switch
- Magnetic Speed Pickup
- High Oil Temperature Switch
- Hour Meter/Start Counter



GEMINI APU

Model T-20G-10C



Technical Data

Minimum Performance
Rating at 15°C (59°) Sea Level
28 SHP

Rating at 39°C (103°F) Sea Level
24 SHP

Maximum Continuous Temperature
716°C (1300°F) EGT

Dry Weight Basic APU
Includes Electronic Control and Engine Oil Cooler (64 lbs)

Maximum Fuel Consumption
(Full Load, Continuous Duty)
39 (pph) 15°C(59°F) Sea Level
39 (pph) 39°C(103°F) Sea Level

Fuels
MIL-T-5624C, JP-4, JP-5, F-40, F-44 (NATO Equivalent) Jet "A"

Oil
MI-L-L-7808, MIL-L-23699 or Commercial Equivalent

Output Pad
One 12,000 rpm, MS-18054

TBO
2000 Hours

Standard Features

- Integral Oil System with Oil Cooler
- Integral Critical Stage Containment
- Improved Turbine Rotating Assembly
- Automatic Start–Solid State Speed Sequencing
- Acceleration Control
- Fully Automated Control System
- Can Combuster with Motor Cup Atomizer
- Starts within 60 Seconds from −54 to 54°C (−65°F to 130°F)
- Operating Attitude; (±10° Roll) or (±10° Pitch with ±20°Roll)
- Overspeed Protection
- Overtemperature Protection
- Low Oil Pressure Protection
- Output Pad Suitable for Most Standard AC and DC Generators
- Fuel Control
- Ignition System
- Fuel Control
- Oil Pressure Regulator
- EGT Thermocouple
- Magnetic Speed Pickup
- Hourmeter

Standard Options

- Fireproof Enclosure with Educator System
- Bracket Mounted Accessory Drive Pad
- Starter Accessory Pad with Light Weight D.C. Starter

Power Systems | SUNDSTRAND AEROSPACE

SAN DIEGO CALIFORNIA 92186 Sundstrand Corporation

Appendix M

Allison

Allison Engine Company P.O. Box 420 Indianapolis, Indiana 46206-0420

June 9, 1995

JSP Industries, Inc.
P.O. Box 12127
Overland Park, KS 66282-2127

Allison Engine Company is pleased to submit the enclosed information in response to your request for information on our turbine programs. I have enclosed information on our Hybrid Vehicle Turbine Engine Technology Support (HVTETS) program with DOE and NASA. The engine shown in cross-section, the AGT-5, makes 120 to 200 horsepower based on configuration. This engine has powered several vehicles, and fits in a standard automotive underhood compartment. The program is focused towards constructing low-cost turbines for automotive applications.

We are also performing efforts under contract with GM to construct a turbine based generator set based on work performed under the HVTETS contract.

Please send me information on the capabilities of your company, and we will consider your company's qualifications for future requirements.

Good luck on the SBIR effort.

Sincerely,

Bob Duge

Bob Duge
Deputy Program Manager,
Hybrid Engines

ROLLS ROYCE AEROSPACE GROUP

HYBRID VEHICLE TURBINE ENGINE TECHNOLOGY SUPPORT

HVTETS

S.G. BERENYI, L.E. GROSECLOSE
ALLISON ENGINE COMPANY

NASA CONTRACT DEN3-336

PRESENTED AT
U.S. DEPT. OF ENERGY
ANNUAL AUTOMOTIVE TECHNOLOGY
DEVELOPMENT CONTRACTORS'
COORDINATION MEETING
OCTOBER 1994

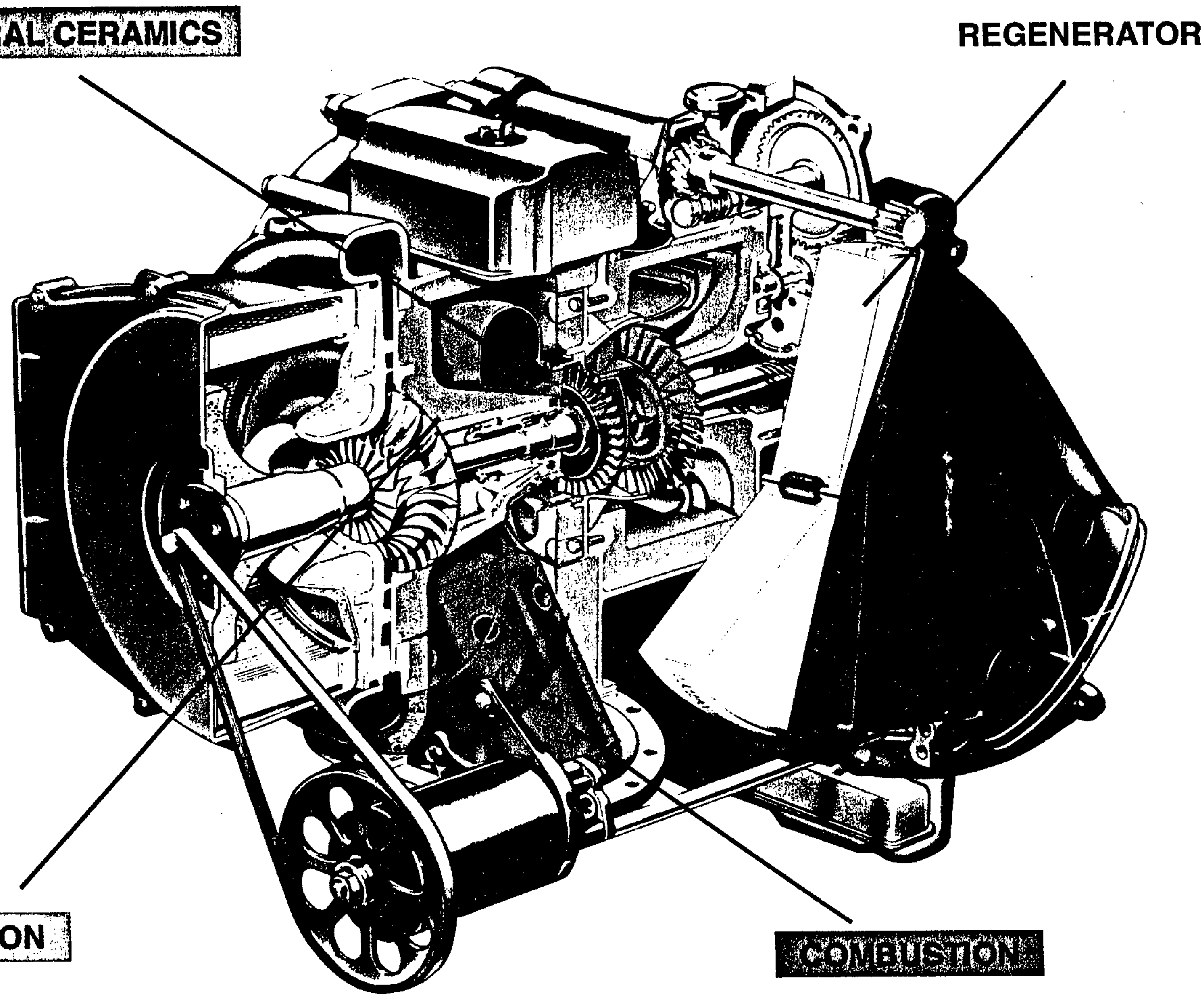
Allison

VS94-2128

135

HVTETS TECHNOLOGIES FOR SUCCESSFUL HYBRID

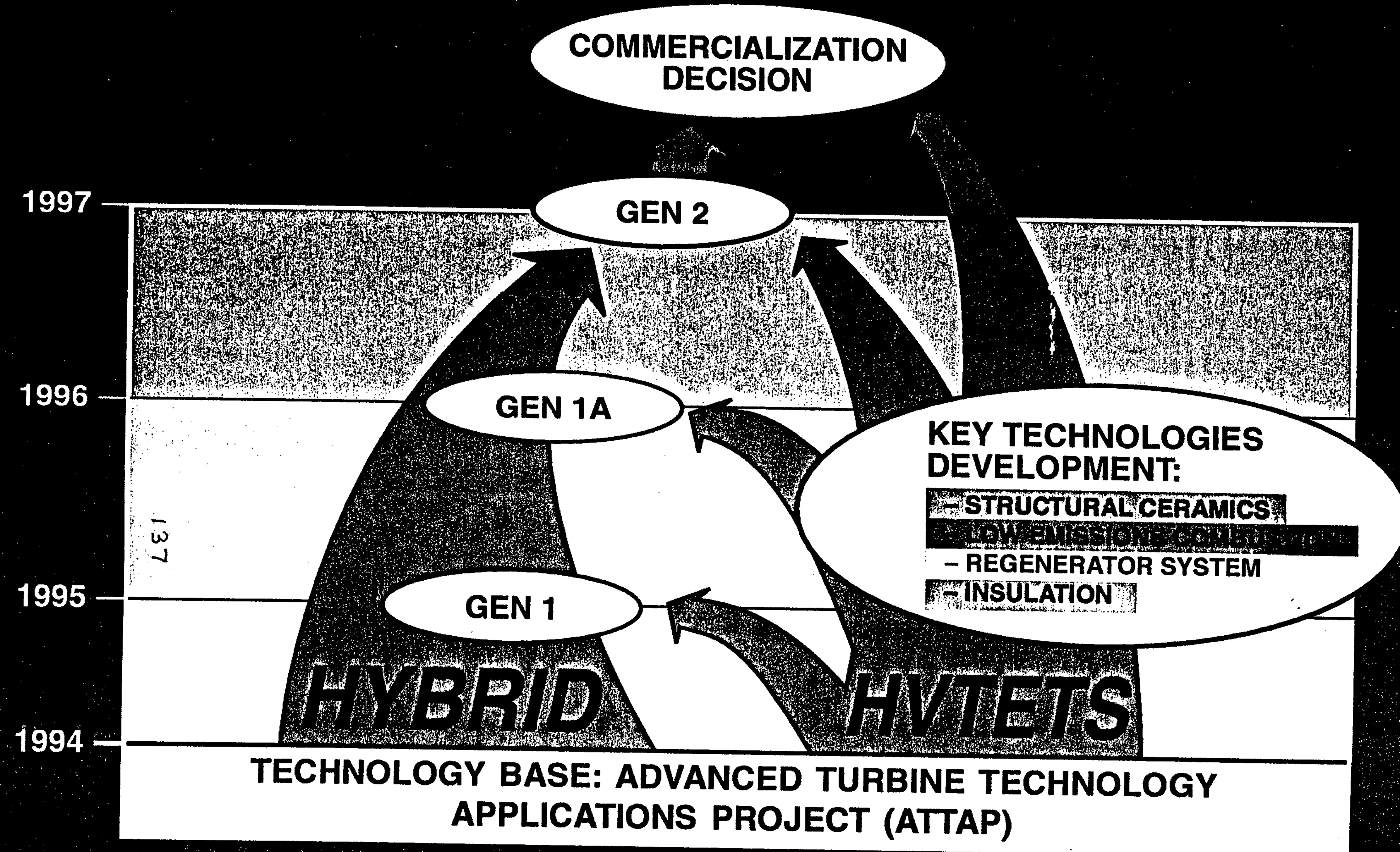
Allison



VS94-1920

HYBRID TURBINE APU DEVELOPMENT

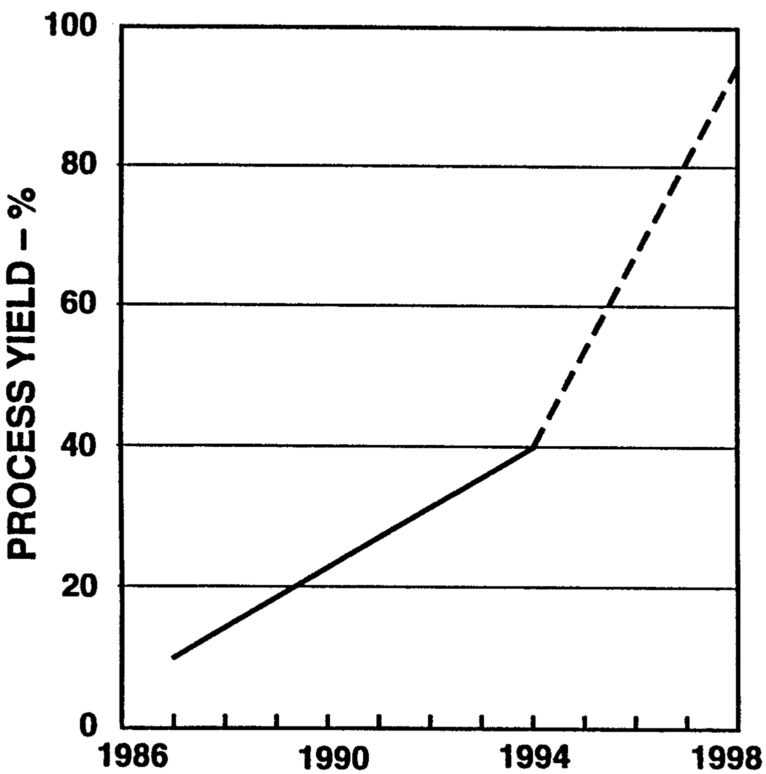
Allison

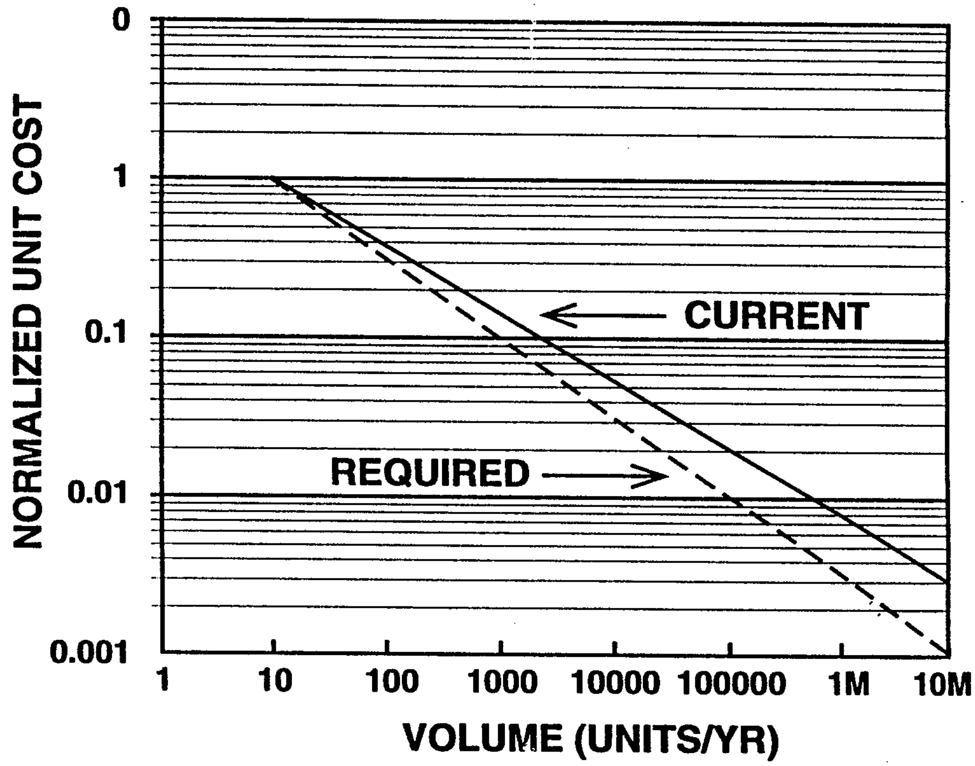


VS94-1919

KEY TECHNOLOGIES DEVELOPMENT

STRUCTURAL CERAMICS FUTURE REQUIREMENTS



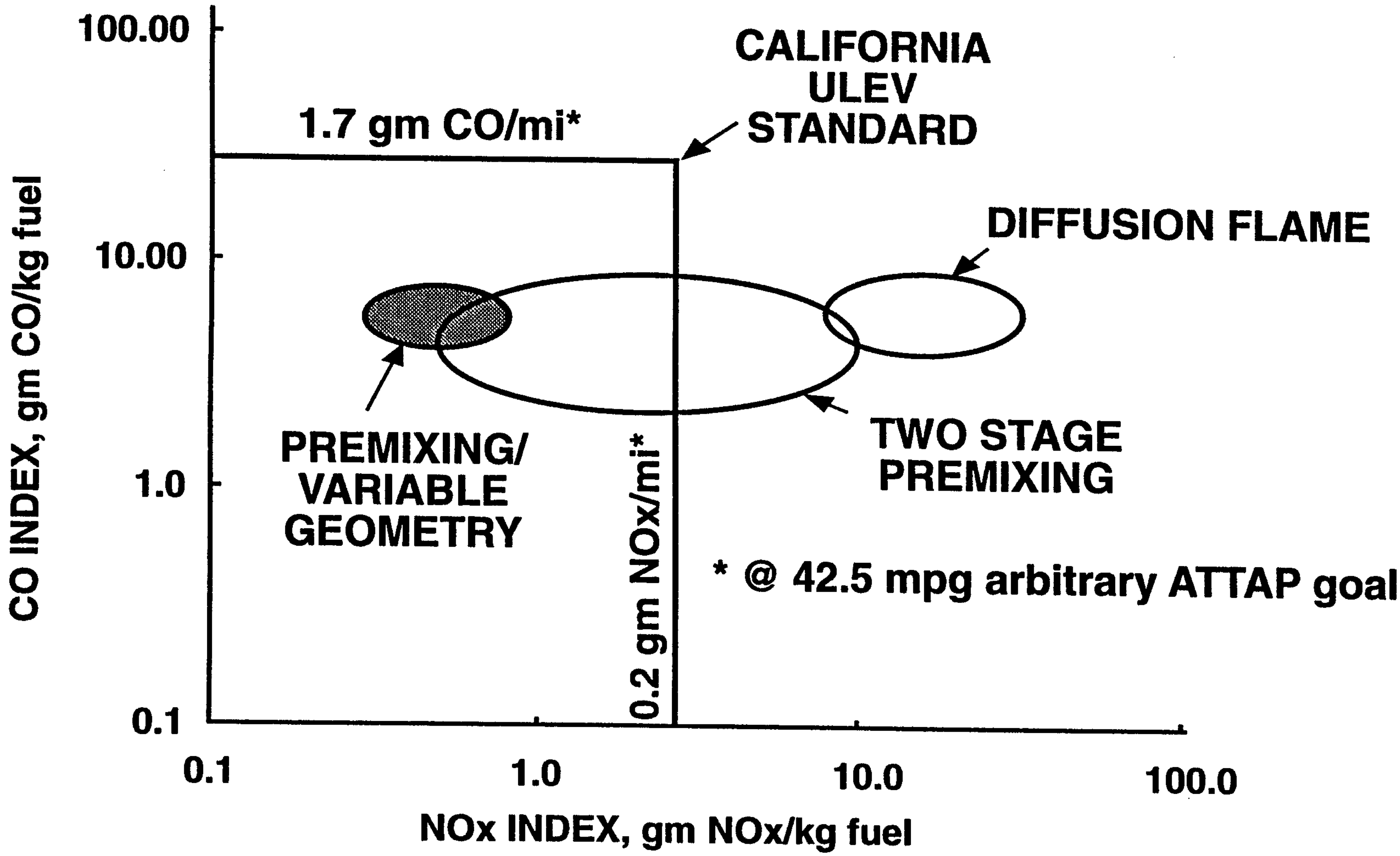


CURRENT = PROJECTED, BASED ON TODAY'S MATERIALS AND PROCESSES.
REQUIRED = IMPROVEMENTS NEEDED TO ACHIEVE GOALS.

VS94-1937

KEY TECHNOLOGIES DEVELOPMENT

LOW EMISSIONS COMBUSTION

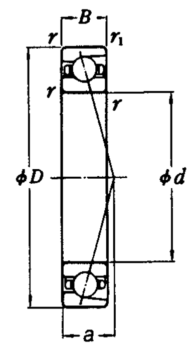


VS94-1929

Appendix N

Super Precision Angular Contact Ball Bearings

7000C Series



Bearing Number	Boundary Dimensions mm					Basic Load Ratings lbs		Basic Load Ratings kgf		Limiting Speeds[2] rpm	
	d	D	B	r[1] min.	r_1[1] min.	C_r	C_{or}	C_r	C_{or}	Grease	Oil
7000 C	10	26	8	0.3	0.15	1200	560	540	254	60000	85000
7001 C	12	28	8	0.3	0.15	1300	650	590	296	53000	75000
7002 C	15	32	9	0.3	0.15	1400	760	635	345	45000	63000
7003 C	17	35	10	0.3	0.15	1500	860	675	390	40000	56000
7004 C	20	42	12	0.6	0.3	2500	1500	1130	665	34000	48000
7005 C	25	47	12	0.6	0.3	2600	1700	1190	755	30000	43000
7006 C	30	55	13	1	0.6	3400	2300	1540	1050	24000	36000
7007 C	35	62	14	1	0.6	4300	3100	1950	1390	22000	30000
7008 C	40	68	15	1	0.6	4600	3600	2100	1620	19000	28000
7009 C	45	75	16	1	0.6	5500	4300	2490	1960	18000	26000
7010 C	50	80	16	1	0.6	5800	4900	2650	2230	16000	24000
7011 C	55	90	18	1.1	0.6	7700	6400	3500	2920	14000	20000
7012 C	60	95	18	1.1	0.6	7900	6900	3600	3150	14000	19000
7013 C	65	100	18	1.1	0.6	8400	7700	3800	3500	13000	18000
7014 C	70	110	20	1.1	0.6	10600	9700	4800	4400	12000	17000
7015 C	75	115	20	1.1	0.6	10800	10200	4900	4650	11000	16000
7016 C	80	125	22	1.1	0.6	13200	12500	6000	5650	10000	15000
7017 C	85	130	22	1.1	0.6	13500	13200	6150	6000	10000	14000
7018 C	90	140	24	1.5	1	16000	15500	7300	7050	9000	13000
7019 C	95	145	24	1.5	1	16500	16400	7500	7450	9000	13000
7020 C	100	150	24	1.5	1	17000	17400	7700	7900	8500	12000
7021 C	105	160	26	2	1	19800	20100	9000	9100	8000	11000
7022 C	110	170	28	2	1	23800	23400	10800	10600	7500	11000
7024 C	120	180	28	2	1	25100	26200	11400	11900	7100	10000
7026 C	130	200	33	2	1	29100	30900	13200	14000	6300	9000
7028 C	140	210	33	2	1	29800	32600	13500	14800	6000	8500
7030 C	150	225	35	2.1	1.1	34000	37900	15400	17200	5600	8000
7032 C	160	240	38	2.1	1.1	38300	43500	17400	19700	5300	7500
7034 C	170	260	42	2.1	1.1	46100	52500	20900	23900	4800	7100
7036 C	180	280	46	2.1	1.1	51500	62000	23300	28100	4500	6700
7038 C	190	290	46	2.1	1.1	55500	69500	25100	31500	4300	6300
7040 C	200	310	51	2.1	1.1	59500	76000	27000	34500	4000	6000

Note: [1] Chamfer dimensions conform to new JIS; however, some chamfer dimensions conforming to old JIS are also used until conversion to new JIS is completed.
[2] For application of limiting speeds, please refer to page 174.

Super Precision Angular Contact Ball Bearings

Interchange Table

	NSK		Fafnir	Barden	NDH
	Standard Type	Ultra-High Speed Type			
ISO Class 4 or (AFBMA ABEC 7)	7200CT* P4 (PA7)	—	2MM200WI*	200H*	Q20200*7
	7200A5T* P4 (PA7)	—	3MM200WI*	2200H*	QH20200*7
	7000CT* P4 (PA7)	00BNC10T*P4 (PA7)	2MM9100WI*	100H*	Q0L00*7
	7000A5T* P4 (PA7)	—	3MM9100WI*	2100H*	QH0L00*7
	7900CT* P4 (PA7)	00BNC19T*P4 (PA7)	2MM9300W0CR*	—	—
	7900A5T* P4 (PA7)	—	—	—	—
ISO Class 5 or (AFBMA ABEC 5)	7200CT* P5 (PA5)	—	—	—	Q20200*5
	7200A5T* P5 (PA5)	—	—	—	QH20200*5
	7000CT* P5 (PA5)	—	—	—	Q0L00*5
	7000A5T* P5 (PA5)	—	—	—	QH0L00*5
	7900CT* P5 (PA5)	—	—	—	—
	7900A5T* P5 (PA5)	—	—	—	—

Notes: 1. Underlined digits (00) vary with bearing size.
2. Asterisks indicate the position of the preload designation for Universal Duplex Bearings in the table below.

Preload Designation for Universal Duplex Bearings

Preload	NSK	Fafnir	Barden	NDH
Light	DUL	DUL	DL	DTL
Medium	DUM	DUM	DM	DTX
Heavy	DUH	DUH	DH	DTT

All conversion data have been carefully checked to assure accuracy; however, omissions and errors are possible.

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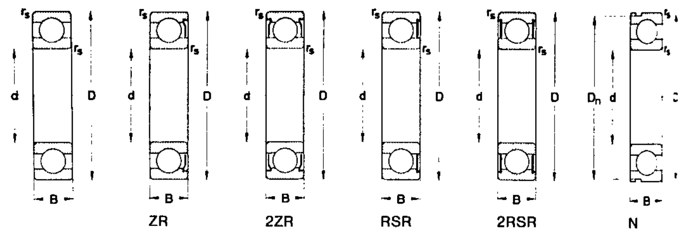
FAG Deep Groove Ball Bearings

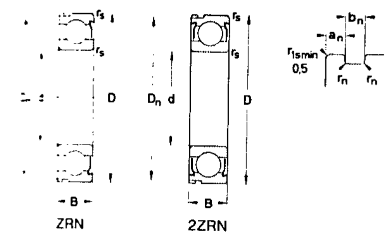
single row



Shaft	d (mm)	D (mm)	B (mm)	r_s min	D_n	a_n	b_n	r_n	Load rating dyn. C (lbs)	stat. C_0 (lbs)	Limiting speed Grease (min^{-1})	Oil (min^{-1})	Number Bearing FAG	Snap ring FAG	Weight ≈ lbs
	10	30	14	0,6					1340	585	17000		**62200.2RSR**		0.093
	10	35	11	0,6					1830	780	22000	28000	**6300**		0.12
	10	35	11	0,6					1830	780	15000		6300RSR		0.12
	10	35	11	0,6					1830	780	15000		**6300.2RSR**		0.12
	10	35	11	0,6					1830	780	22000		6300ZR		0.12
	10	35	11	0,6					1830	780	22000		**6300.2ZR**		0.12
	10	35	11	0,6					1830	780	22000		6300.2ZR.C3		0.12
12	12	21	5	0,3					405	216	32000	38000	61801T		0.014
	12	28	8	0,3					1140	530	26000	32000	**6001**		0.045
	12	28	8	0,3					1140	530	26000	32000	**6001.C3**		0.045
	12	28	8	0,3					1140	530	17000		**6001RSR**		0.045
	12	28	8	0,3					1140	530	17000		**6001.2RSR**		0.045
	12	28	8	0,3					850	395	26000	32000	**6001Z15**		0.045
	12	28	8	0,3					850	395	17000		**6001Z15.2RSR**		0.045
	12	28	8	0,3					1140	530	26000		**6001ZR**		0.045
	12	28	8	0,3					1140	530	26000		**6001.2ZR**		0.045
	12	28	8	0,3					1140	530	26000		**6001.2ZR.C3**		0.045
	12	30	8	0,3					1140	530	26000	32000	**16101**		0.059
	12	32	10	0,6					1560	695	24000	30000	**6201**		0.128
	12	32	10	0,6					1560	695	24000	30000	**6201.C3**		0.128
	12	32	10	0,6	30,15	2,06	1,35	0,4	1560	695	24000	30000	6201N	SP32	0.128
	12	32	10	0,6					1560	695	16000		**6201RSR**		0.128
	12	32	10	0,6					1560	695	16000		**6201.2RSR**		0.128
	12	32	10	0,6					1560	695	16000		**6201.2RSR.C3**		0.128
	12	32	10	0,6					1160	520	24000	30000	**6201Z15**		0.128
	12	32	10	0,6					1160	520	16000		**6201Z15.2RSR**		0.128
	12	32	10	0,6					1560	695	24000		**6201ZR**		0.128
	12	32	10	0,6					1560	695	24000		**6201ZR.C3**		0.128
	12	32	10	0,6	30,15	2,06	1,35	0,4	1560	695	24000		6201ZRN	SP32	0.128
	12	32	10	0,6					1560	695	24000		**6201.2ZR**		0.128
	12	32	10	0,6					1560	695	24000		**6201.2ZR.C3**		0.128
	12	32	14	0,6					1560	695	16000		**62201.2RSR**		0.106
	12	37	12	1					2200	950	20000	26000	**6301**		0.134
	12	37	12	1					2200	950	20000	26000	**6301.C3**		0.134
	12	37	12	1					2200	950	13000		6301RSR		0.134
	12	37	12	1					2200	950	13000		**6301.2RSR**		0.134
	12	37	12	1					2200	950	20000		**6301ZR**		0.134
	12	37	12	1					2200	950	20000		**6301.2ZR**		0.134
	12	37	12	1					2200	950	20000		6301.2ZR.C3		0.134
15	15	24	5	0,3					465	285	30000	36000	61802T		0.01[illegible]
	15	32	8	0,3					1250	640	24000	30000	**16002**		0.06

FAG Deep Groove Ball Bearings

single row



Shaft	d (mm)	D (mm)	B (mm)	r_s min	D_n	a_n	b_n	r_n	Load rating dyn. C (lbs)	stat. C_0 (lbs)	Limiting speed Grease (min^{-1})	Oil (min^{-1})	Number Bearing FAG	Snap ring FAG	Weight ≈ lbs
	15	32	9	0,3					1250	640	24000	30000	**6002**		0.063
	15	32	9	0,3					1250	640	24000	30000	**6002.C3**		0.063
	15	32	9	0,3					1250	640	15000		**6002RSR**		0.063
	15	32	9	0,3					1250	640	15000		**6002.2RSR**		0.063
	15	32	9	0,3					930	475	24000	30000	**6002Z15**		0.063
	15	32	9	0,3					930	475	15000		**6002Z15.2RSR**		0.063
	15	32	9	0,3					1250	640	24000		**6002ZR**		0.063
	15	32	9	0,3					1250	640	24000		**6002.2ZR**		0.063
	15	32	9	0,3					1250	640	24000		**6002.2ZR.C3**		0.063
	15	35	11	0,6					1730	850	20000	26000	**6202**		0.095
	15	35	11	0,6					1730	850	20000	26000	**6202.C3**		0.095
	15	35	11	0,6	33,17	2,06	1,35	0,4	1730	850	20000	26000	6202N	SP35	0.095
	15	35	11	0,6					1730	850	14000		**6202RSR**		0.095
	15	35	11	0,6					1730	850	14000		**6202RSR.C3**		0.095
	15	35	11	0,6					1730	850	14000		**6202.2RSR**		0.095
	15	35	11	0,6					1730	850	14000		**6202.2RSR.C3**		0.095
	15	35	11	0,6					1320	630	20000	26000	**6202Z15**		0.095
	15	35	11	0,6					1320	630	14000		**6202Z15.2RSR**		0.095
	15	35	11	0,6					1730	850	20000		**6202ZR**		0.095
	15	35	11	0,6					1730	850	20000		**6202ZR.C3**		0.095
	15	35	11	0,6	33,17	2,06	1,35	0,4	1730	850	20000		6202ZRN	SP35	0.095
	15	35	11	0,6					1730	850	20000		**6202.2ZR**		0.095
	15	35	11	0,6					1730	850	20000		**6202.2ZR.C3**		0.095
	15	35	11	0,6	33,17	2,06	1,35	0,4	1730	850	20000		6202.2ZRN	SP35	0.095
	15	35	14	0,6					1730	850	14000		**62202.2RSR**		0.118
	15	42	13	1					2550	1200	18000	22000	**6302**		0.188
	15	42	13	1					2550	1200	18000	22000	**6302.C3**		0.188
	15	42	13	1	39,75	2,06	1,35	0,4	2550	1200	18000	22000	6302N	SP42	0.188
	15	42	13	1					2550	1200	12000		**6302RSR**		0.188
	15	42	13	1					2550	1200	12000		**6302.2RSR**		0.188
	15	42	13	1					2550	1200	12000		6302.2RSR.C3		0.188
	15	42	13	1					2550	1200	18000		**6302ZR**		0.188
	15	42	13	1					2550	1200	18000		**6302ZR.C3**		0.188
	15	42	13	1					2550	1200	18000		**6302.2ZR**		0.188
	15	42	13	1					2550	1200	18000		6302.2ZR.C3		0.188
	15	42	17	1					2550	1200	12000		**62302.2RSR**		0.239
17	17	26	5	0,3					500	325	28000	34000	61803T		0.018
	17	35	8	0,3					1340	735	22000	28000	**16003**		0.07
	17	35	8	0,3					1340	735	22000	28000	**16003.C3**		0.07
	17	35	10	0,3					1340	735	22000	28000	**6003**		0.083
	17	35	10	0,3					1340	735	22000	28000	**6003.C3**		0.083
	17	35	10	0,3					1340	735	13000		**6003RSR**		0.083
	17	35	10	0,3					1340	735	13000		**6003.2RSR**		0.083
	17	35	10	0,3					1020	550	22000	28000	**6003Z15**		0.083
	17	35	10	0,3					1020	550	13000		**6003Z15.2RSR**		0.083

When selecting a bearing preference should be given to **those in bold-faced print** thus taking advantage of the FAG Standard Programme. For the availability of other than standard designs please consult FAG.